AN ETHNOGRAPHICALLY INFORMED ANALYSIS OF DESIGN INTENT COMMUNICATION IN BIM-ENABLED ARCHITECTURAL PRACTICE

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AN ETHNOGRAPHICALLY INFORMED ANALYSIS OF DESIGN INTENT COMMUNICATION IN BIM-ENABLED ARCHITECTURAL PRACTICE

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To my parents, loving wife and two sons

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SUMMARY

The building information model (BIM) is assumed to encompass all the required parameters, constraints, rules and attributes about a design product and process for AEC practitioners in a way comprehendible by all disciplinary participants sharing the model and that communicates their goals, needs and intentions, besides communicating design information. The socio-cognitive interactions that occur in the workplace however such as the negotiation of meaning, argumentation and the active participation of multiple communities of practice imply that there are discrepancies between what is exchanged among participants as design information when sharing a building model and what is exchanged as goals, needs and possibly conflicting intentions and interests when sharing a common ill-structured problem.

The dissertation presents the findings of an ethnographic study that was conducted with the aim of developing a deep understanding of how design intent is communicated in BIM-enabled practice in the context of an architectural project. The dissertation study was based on the broad question: what are the affordances and limitations that exist in BIM-enabled architectural practice in terms of communicating design intent among teams of designers working in interdisciplinary collaborative environments*?* The study also addressed related issues such as: do the current exchange mechanisms in BIM convey what design teams really intended? Is there critical design knowledge resulting from the argumentative process that is not conveyed using BIM data exchange capabilities and authoring tools? How is the knowledge that is produced in internal design thinking sessions, meetings or informal communication transferred to

other participants? To what extent should that information be embedded in the shared building model? How effective is a shared building model in practice in terms of communicating product data, design decisions, tacit knowledge and expertise? To what extent is it hindered by tool complexity, learning challenges, the need to express some forms of communication informally, and the urge to address flexibility in design?

The major conclusions of the dissertation include the following: (1) affordances and limitations of BIM differ according to individuals, disciplines and communities. Affordances included affordances with respect to the tool such as visualization capacity and parametric flexibility, and affordances with respect to collaboration such as coordination of information and conflict resolution. Limitations included incompatibility among tools, the cost of 3D modeling for participants and teams, the need for supplementary representations and communication channels, and conceptualization limitations; (2) the communication of design intent involves not only interdisciplinary interaction between architects and consultants, but multiple and overlapping communities of practice that embrace interdisciplinary, intradisciplinary and non-disciplinary interaction, in addition to emergent communities that develop along the course of a project, focus on specific issues and involve members of different communities, (3) the BIM model can be described in terms of states that denote the level of its completeness and correctness and that describe how effective it is in conveying and capturing the intent of participants in the context of their practices and interactions. These states underscore issues such as the potentially unconscious design decisions imposed by the rigid structure of BIM tools, the incorrect modeling of building elements due to inexperience with tools, the loss or misrepresentation of information among participants due to incompatibilities between tools and interoperability problems, the lack of standard conventions for building elements that facilitate understanding the information needs of other participants, the partial representation of building model elements for the purpose of efficiency and reduction of modeling load, the ruling out of some of the underlying assumptions embedded within modeling or analysis tools, the required channels of communication external to the process of model exchange, and the need for forms of representation to supplement the BIM model for better conceptualization; (4) the shared BIM model can be represented partially as a boundary object with different relative weights and meanings in each design stage and for each community of practice. It represented a different value for members of different communities; (5) the BIM model presented an amplification of the participation and reification processes in the workplace; multi-membership and mutual recognition among participants belonging to different and overlapping communities of practice augmented the sense of participation, while the model provided different values and levels of interpretation for members of different primary and secondary communities of practice through reification; (6) in principle, the BIM model as a shared repository of information and a boundary object is assumed to take into account all participation and reification activities. However, the convoluted meaning making processes, and the goals, needs and intentions of multi-member communities entail much more interaction patterns that are not necessarily captured in current BIM systems; and (7) the differences in multi-memberships, values of BIM for different members, participation and reification activities, and the structure of primary and secondary communities of practice, should all be accounted for in technology development efforts in the larger population of AEC firms and practices.

CHAPTER 1

INTRODUCTION

Building information modeling (BIM) has impacted the way architects and designers manipulate their designs, both on the individual level and in collaborative contexts. It has generally caused a transformation in the epistemic culture of architectural practice by introducing machine-readable applications that focus on the richness of information embedded computationally in designs rather than mere geometry or presentation. This culture is continuously developing new properties for its participants, resources, and knowledge construction mechanisms. BIM has begun to transform the way designers formulate their ideas, especially in early ideation phases. This is primarily due to the concept of the virtual building and the ability to construct, simulate and test design environments before constructing them in the real world. This has changed the structure of the conventional design process, where most design optimization efforts began to lie in the ideation phase rather than later phases, adding more complexity to problem solving in terms of cognitive processes, and in particular in collaborative environments.

The premise in BIM-enabled practice is that effective communication and collaboration can be achieved by specifying data exchange patterns between multiple building product models. This is achieved through interoperability, which describes the need to pass data between software applications to enable the contribution of different participants and applications to building model data. New patterns of communication of design knowledge and intent have emerged in architectural practice with the implementation of these data exchange routines. This has affected how different design team members express and transfer important design information and the reasoning behind design decisions. This research explores how BIM is influencing the mechanisms of design intent communication in architectural practice.

1.1 Problem Formulation

The design and development of architectural design projects in collaborative contexts encompasses a variety of design requirements, decisions, constraints, criteria, and alternatives. This adds to the project complexity, as the process of managing, recording and keeping track of all these variables becomes more convoluted. At the same time, the design process requires efficient planning and control to reduce the effects of this complexity. The issues of communicating design knowledge among the various stakeholders in the design process and keeping track of the thinking process and the reasoning underlying design decisions have always been a concern in the history of architectural practice. The premise was that it was not only enough to document design decisions, but that it was important to develop the design intent or rationale underlying those decisions in a collaborative fashion such that it could be accessible by multiple entities at different phases of the design process for different purposes.

Many researchers consider that capturing and documenting design intent offers great support to designers by structuring design problems and affording possibilities and opportunities for exploration of design alternatives (Guindon et al., 1987; Prabhakar and Goel, 1998). Systems that take into account the communication of design intent are argued to provide a robust basis for reasoning and discussion among designers working in collaboration. Before introducing digital representations in design, the knowledge produced and communicated during the design process was not all formalized. Much of it rested in the minds of multiple entities in design teams. Design intent was not completely documented or captured, which resulted in a time-consuming process of communication among collaborating design teams to understand each other's work (Klein, 1993).

A considerable amount of progress has been made on the development of approaches and systems to represent design intent since the 1970s and 1980s. These approaches emerged out of different disciplines. Some efforts focused on basic observations about the design process (Ullman et al., 1988) while others were concerned with proposing frameworks and approaches to capture, represent and retrieve design rationale. A number of important prototypes have been developed (Kunz and Rittel, 1970; Fischer et al., 1989; Conklin and Yakemovic, 1991; Lee and Lai, 1991; McCall, 1991; Henderson, 1993; Ramesh and Sengupta, 1995; Brazier et al., 1997; Shipman and McCall, 1997; Garcia and de Souza, 1997; Chung and Goodwin, 1998; Rosenman and Gero, 1999; Hayes et al. 2001; Brissaud et al., 2003), but only a few design rationale systems have made it into practical use in industry (Fenves, 2001; Baysal et al., 2004).

The conceptual basis for developing these systems did not stem from one common approach, but originated from different concepts and perspectives in design theory, such as situated action (Schon, 1987), symbolic information processing (Simon, 1996), pattern language (Alexander, 1979), wicked problems (Rittel and Weber, 1984), and others. Rittel and Weber's (1984) perspective focuses on design as an argumentative process where different people with different goals and different views of representing a wicked (or ill-structured) design problem come to a collective understanding of explaining that problem by means of collaboration.

Capturing and recording argumentation has been underscored as beneficial to architectural design and designers with respect to collaborating with other participants in the design as well as communicating with existing artifacts and past designers (Fischer et al., 1991). Models originally developed to expose the structure of argumentation in the design process, including issue-based information systems (Kunz and Rittel, 1970), highlighted *issues*, *positions*, and *arguments* as the main components of this structure. *Issues* represent questions or problems that designers face along the design process. *Positions* are the responses of different participants to these issues, and they are either justified or criticized by means of *arguments*. Seen in the context of AEC interdisciplinary practice, each of the participating teams (owner, architectural design team, structural engineering team, etc.) has its individual and collective issues, positions and arguments to tackle the design problem in hand (figure 1.1).

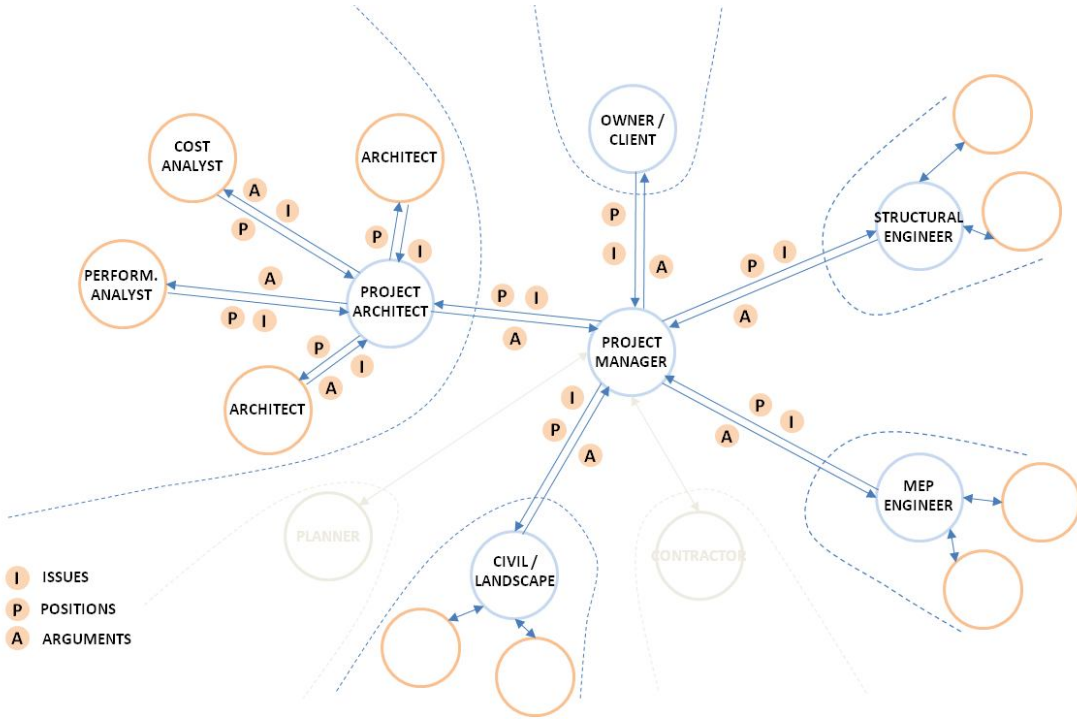

Figure 1.1. Author's interpretation of Rittel and Weber's (1984) view of design as an argumentative process, as seen in AEC interdisciplinary practice

One of the efforts that have made design intent readily accessible to all participating entities or collaborators in the AEC industry by means of rich representations is building information modeling (BIM). The claim about BIM was that all required information is embedded in a model which can be shared by all collaborators through repositories and databases, and this model carries all the required parameters, constraints, rules and attributes about the "design product" in a way comprehendible by all participants, and that communicates design knowledge. This was assumed to present a different method of representing design intent between interdisciplinary teams, where teams could understand what their collaborators intended, and must respectively attempt to communicate their intent in a way that is comprehendible to others.

In BIM, the process of exchanging data from one design team to the other or sharing building model data among all participants entails the definition of parameters, constraints and rules besides the model geometry. This requires the exchange of specific information and a clear definition of the boundary of the shared space of information. In the workplace context however, most of the effort lies in the argumentative process between participants in order to negotiate that boundary in the first place, seen through design meetings, informal conversation, and other forms of socio-cognitive interaction. This implies that these participants "exchange" different issues, positions, and arguments in the process of "sharing" a common ill-structured problem based on their different views of that problem and possibly conflicting intents (figure 1.2).

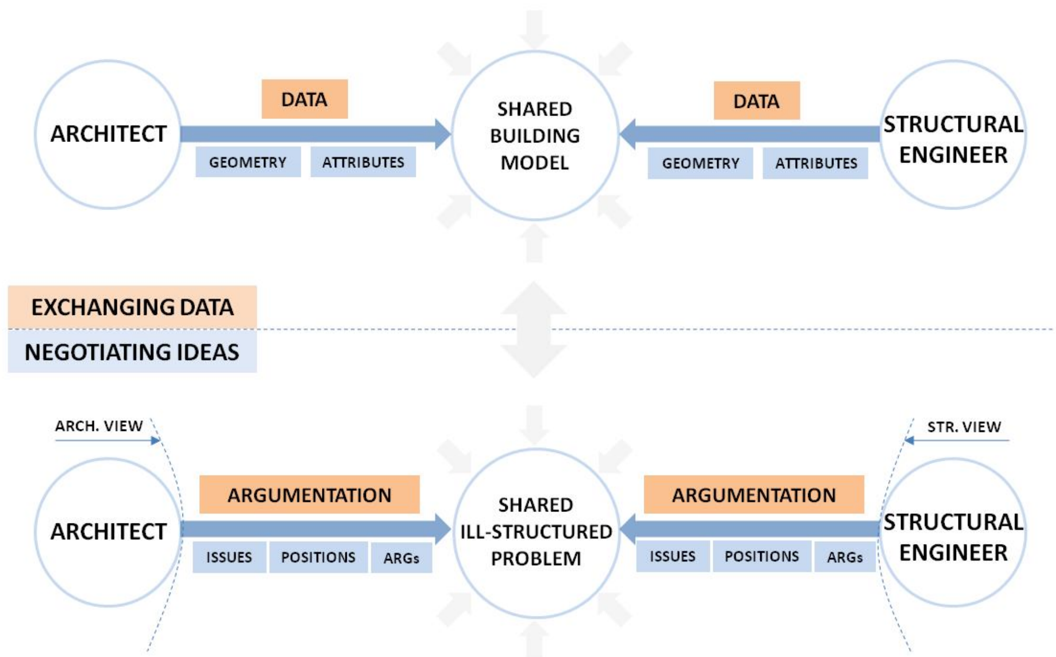

Figure 1.2. The gap between data exchange mechanisms in BIM and the argumentative process in AEC interdisciplinary practice

According to Fischer et al. (1991), if a system or process were developed to record or expose the structure of this argumentation, the communication of design intent between these different participants will be facilitated. To the author's knowledge, there is no comprehensive effort that has yet identified the gap between (1) the capabilities of data exchange mechanisms in BIM, as a process that offers rich representations, in exposing argumentation structures among AEC design teams working in collaboration;

and (2) what these teams require in practice with respect to communicating their views, needs, issues, positions and arguments. Studies that address AEC collaboration in BIM and interoperability focus on developing systems for design coordination using process management and database transactions (Kim et al., 1997; Jeng and Eastman, 1998; Kalay, 1998; Jeng, 1999; Jeng and Eastman, 1999), embedding intelligence in BIM models by means of IFC development (Pham and Dawson, 2003; Halfawy and Froese, 2002), information delivery manual (IDM) specifications for accurate exchange of domain-specific information (Eastman et al., 2010; Aram et al., 2010), and other approaches. These approaches focus on specific datasets of information for exchange between AEC practitioners, taking into consideration the conceptual framework of their different disciplines, and highlight interdisciplinary collaboration between those disciplines. They do not investigate however into the mechanisms of interaction between members of each of the different disciplines during their day-to-day communication, exchange of ideas and design development practices. Other studies (Aranda-Mena et al., 2008b; Gu et al., 2008; Hartmann et al., 2009; McGraw Hill, 2009) use case studies and surveys to gain insight into the practices of AEC practitioners and their expectations regarding adopting BIM. Although these studies provide some feedback as to the mechanisms of interaction within AEC firms, they do not fully describe how socio-cognitive aspects of interaction take place in *communities of practice* (Wenger, 1998), and whether the expectations, goals, intentions and needs of members of different communities, that embrace often conflicting interests, are met in BIM workflows, processes and tools to date.

1.2 Research Questions

The broad question that still remains unanswered is:

What are the affordances and limitations that exist in BIM-enabled architectural practice in terms of communicating design intent among teams of designers working in interdisciplinary collaborative environments?

To answer this and other questions, this research is concerned with examining the nature of argumentation and negotiation in the growing BIM-enabled architectural practice. To understand how this takes place, it is crucial to study the different AEC teams and participants and their issues, positions and arguments throughout design phases in the real world; i.e. in the workplace, and not just studying design activities taken out of context. In doing so, the study attempts to address the following questions, and will continue to address other questions generated along the course of the observation:

1. To what extent does BIM provide an effective method for communicating design intent? Under what circumstances is design intent fully captured and represented in BIM? Which aspects are important to capture and which are irrelevant?
2. What are the affordances and constraints that currently exist in BIM-enabled practice, seen through the process of argumentation and negotiation of ideas in design thinking and discussion sessions, informal conversation and meeting sessions?
3. Do the current data exchange capabilities in BIM provide a method for exposing argumentation structures and capturing design intent between interdisciplinary teams? Do they convey what design teams really intended?
4. Is there critical design knowledge resulting from the argumentative process that is not conveyed using BIM data exchange capabilities and authoring tools?
5. How is the knowledge that is produced in internal design thinking sessions, meetings or informal communication transferred to other participants? To what extent should that information be embedded in the shared building model?
6. How effective is a shared building model in practice in terms of communicating product data, design decisions, tacit knowledge and expertise?

To what extent is it hindered by tool complexity, learning challenges, the need to express some forms of communication informally, and the urge to address flexibility in design?

1.3 Research Goals and Objectives

The main goal of the dissertation research is to explore how design intent is communicated among AEC design teams within the context of BIM-enabled practice. This goal entails exploring the goals and needs of AEC teams in practice in terms of communicating their issues, positions and arguments, and observing the mechanisms of BIM information exchange and interoperability. This is achieved through the following objectives. The first objective involves the investigation of systems, work routines, and information exchange mechanisms that support the capture, representation, communication, documentation and retrieval of design intent and design knowledge across team structures, tools and representations. As the dissertation study takes place in the context of architectural practice, it implies observing the interaction and collaboration mechanisms with other parties including clients and AEC teams. The second objective is concerned with exploring the nature of collaboration and interaction within firms and identifying what different teams or communities of practice require to accomplish effective collaboration both within their specific domains and with other disciplines.

The third objective involves understanding the concepts of BIM and interoperability, and exploring what they offer to collaboration routines, and where they belong in relation to the spectrum of systems developed for communicating design intent. The main focus here, which emerges throughout the study, is identifying the affordances and limitations in these technologies, specifically what BIM might lack in terms of supporting argumentation structures and interaction within and across disciplines. The fourth objective is concerned with identifying patterns of argumentation, negotiation of ideas, work routines, and interaction mechanisms that take place among design team members in BIM-enabled practice in the context of a real-world project. This requires a long-term observation of the practices that occur in the workplace, and not just a quick survey of a group of firms, in order to capture the essence of interaction among teams and how they communicate design intent in BIM.

1.4 Description of Study

The dissertation research was primarily concerned with examining the nature of argumentation and negotiation in the growing BIM-enabled architectural practice. To understand how this takes place, a study was conducted to study how AEC participants, residing in different *communities of practice* (Wenger, 1998), used the shared BIM model in the workplace. This study involved a long-term observation of the practices and interactions of its participants in the context of an architectural project in AEC firms. The process of selecting candidate firms for this study relied on two sources: 1) The "Building Design + Construction" (BD+C) Annual Giants 300 List, and 2) The General Services Administration (GSA) Nationwide BIM Services Indefinite Delivery Indefinite Quantity (IDIQ) Contract Awards. After reviewing architectural firms from both sources, the selection process involved further criteria including the size of the firm, location, types of services, specialty and area of expertise, scale of projects, type of projects, number of staff, availability of BIM projects, and the structure of the firm. For the purpose of this study, one firm was selected.

This study focuses on a detailed observation of a single architectural project. This will be referred to as the SG project. The selection of the project depended on a number of factors, such as the availability and nature of BIM projects within the firm and other participating disciplines, the scope and level of detail of BIM implementation in each discipline, the nature and method of collaboration and communication between teams, and others. The study was conducted over the course of 8 months which was the duration of the SG project starting from schematic design through construction documents.

The SG project was a three storey 80000 square foot technical college medical technology building. It included lecture spaces such as auditoriums and classrooms, laboratory spaces such as chemistry and biology labs, physical therapy, dental, opticianary, nuclear medicine and radiation therapy labs, public circulation and lobby spaces, and service spaces. Two major incidents affected the project workflow and design decisions. Due to market circumstances and the economy of construction, the architectural team projected that the client could "*buy more building*" at that point of time, implying that the 80000 square foot program of the building could potentially and easily grow to be a 100000 square foot program with no increase in funding allocated from the state. After being encouraged by the client and facilities group to increase the square footage by 20000 square feet, and after the team was almost 95% through with the program and with schematic design, the state office of planning and budget informed the client and the team that they were not allowed to exceed the approved square footage. There was a 2 months setback along this review process where the team stopped working on the project awaiting the final decision. Following that, the program and mass of the building had to be revised by the team with the client and technical college system. At the beginning of design development, the client (head of the university) stepped down and the new client made substantial changes to what he preferred as the form and look of the building. Instead of a traditional approach that the team had worked on throughout schematic design, the new head of university preferred a modern look and approach for the building. This again affected the design and workflow process.

The main disciplinary participants in this study included the architectural firm, a structural engineering firm, an MEP (mechanical engineering plumbing) firm, a civil and landscape firm, and an A/V (audiovisual) firm, in addition to two cost estimation teams and one sustainability analysis team. The architectural firm is specialized in the design, programming and master planning of architectural projects including museums, arts centers, government buildings, laboratories, corporate headquarters, education facilities and conference facilities.

During the observation, the main members of the architectural team included a project architect (A1), a project manager (A2), one interior designer (A3), one intern architect (A4), and one architect (A5). The architectural team members were working under the supervision of one principal architect (P1) who was in charge of the main design decisions in the project. Of the team members, three were female and two were male; the principal architect was male. One of the architects (A5) joined halfway through the project, in the design development phase. Apart from the architectural team, a laboratory designer was assisting the team concerning programmatic requirements related to medical technology buildings. In-house consultants in the firm who were directly involved in this project included a sustainability analyst (E1) and a cost estimator (C1). There were also two architects fully dedicated to technical support; a BIM manager (B1) and a BIM specialist and staff architect (B2).

The main members of the structural team included a project manager (S1) and a lead structural engineer (S2). The structural team members were working under the supervision of a senior principal whose main task was to oversee the project and review the progress periodically. All team members were male. Apart from the structural team, another structural engineer (S3) was fully dedicated to technical support on this project with respect to the BIM tool that the firm used (Revit Structure).

The main members of the mechanical/HVAC department included a project manager (M3) and one mechanical engineer (M4) who had joined halfway through the project. The plumbing department included a project manager (M1) and a plumbing engineer. The electrical department included a project manager (M2) and an electrical engineer (M6). The project manager in the electrical department (M2) was the primary point of contact and project manager representing the MEP team. All team members were male. Apart from the MEP team, the firm had hired an architect (M5) who was fully dedicated to technical support on this project with respect to the BIM tool that the firm used (Revit MEP). The main members of the A/V team included a project director (V1) and one lead A/V engineer (V3). Both team members were male. Apart from the A/V team, the director of A/V design oversees the engineering department and handles technical issues (V2). He is also a CAD and BIM tool expert. The main members of the civil and landscape team included a senior engineer (L1), a project manager (L2) and two drafters. All team members were male.

The dissertation is organized into 8 chapters including the introduction chapter. Chapter 2 presents a review of supporting literature. Chapter 3 presents the main methods employed in the dissertation, including an overview of ethnographic research and its significance, grounded theory coding and analysis, persona and thick description literature and significance, result reliability and verification, and relevance to research in BIM and the AEC industry. Chapter 4 introduces the main personas that were identified in the study based on their salient features related to the research questions. Chapter 5 presents the types of interaction that were identified in the study in the form of specific events related to the research inquiry, including interdisciplinary, intradisciplinary and non-disciplinary interaction. Chapter 6 discusses the BIM shared project model in light of the findings of the study by revisiting different interfaces of interaction among its participants and teams. Chapter 7 discusses the research observations in the larger context of BIM-enabled practice to provide a basis for transferability to other contexts or settings. Chapter 8 concludes by summarizing the research study and discussing recommendations and future work.

CHAPTER 2

LITERATURE REVIEW

This chapter provides a literature review of topics related to the basic inquiry of the research. Section 2.1 presents an overview of building information modeling (BIM), introducing its main concepts, properties and applications in practice. It also discusses how the literature describes BIM support for interdisciplinary collaboration and interoperability. Section 2.2 discusses literature related to design intent research. The main concepts and interpretations of design intent are introduced, followed by the main cognitive and social dimensions of design intent in the literature and how CAD and BIM systems support communication of design intent to date.

2.1 Building Information Modeling

2.1.1 Definitions and Views

Definitions of building information modeling (BIM) in industry vary by discipline or profession. It is sometimes seen as a design and information documentation process, sometimes it is viewed as just a tool, while others may see it as a totally new approach in the architecture, engineering and construction practice which aims at advancing the profession and would thus require a transformation in the way policies, contracts and relationships are conventionally established (Aranda-Mena et al., 2008a). The term *building information modeling* has emerged through a succession of synonymous concepts like object oriented modeling, project modeling, virtual design and construction, virtual building, virtual prototyping, integrated project databases and others. Definitions have been proposed for the term according to one of those concepts or views.

Gann et al. (1996) refer to the concept of a single project database to which all participants refer throughout the whole design, construction, operation and maintenance.

Fisher et al. (1997) describe the term project modeling as object modeling that is applied to a design project and carries information that is more than mere geometry. Salford University proposed the term nD model as an extension of the building information model to comprise aspects of information that are needed at each phase of a project lifecycle (Construct IT, 2002). The latest term "building information modeling" became popular upon Jerry Laiserin's definition which highlighted the capability of using, reusing and exchanging information. He emphasized the concepts of clear communication, maintaining design intent, and having the advantage of higher analytic tools rather than just rendering or exchanging electronic versions of paper documents. Subsequent definitions shared the concept of BIM as a digital representation of the building. The buildingSMART (2011) organization views BIM as a digital representation of physical and functional characteristics of a facility, which is a resource of shared knowledge that introduces a reliable foundation for design decisions during the facility lifecycle. The Contractors' Guide to BIM (AGC, 2006) extends this definition within the notion of virtual design and construction (VDC) to describe BIM as a data-rich, object-oriented, intelligent and parametric digital representation of the facility from which views and information suitable to multiple users can be extracted and analyzed.

Succar et al. (2007) argued for the emerging and revolutionary role of BIM in practice, as it produces a technological and procedural shift that affects all participants in the AEC industry. They also highlight the interaction between processes, technologies and policies that takes place in BIM to generate a consistent methodology that manages design and project information throughout a building lifecycle. At the same time, they point out the issues related to semantics, meaning and interpretation that result from the engagement of multiple participants in the process.

2.1.2 Transformation from CAD to BIM

Design concepts and information were conventionally exchanged among different stakeholders and captured using notes, sketches and physical models, and were validated by means of client meetings and design brief development. Computers were used at late design phases for documentation purposes following the approval of clients for a selected design scheme. 2D CAD presented a method for drafting which replicated manual drawing techniques, such as plans, elevations, cross sections and perspectives, which had existed long before computers were invented. CAD tools only supported conventional methods and added very little to designers' capabilities. The knowledge of the average, and often experienced, user of basic tool functionalities and of the design tasks did not necessarily guarantee an efficient communication of design information to other participants (Bhavnani and John, 2000). Subsequent versions of CAD tools only enhanced and extended the technology behind earlier versions, but features remained similar. Communicating design information among various stakeholders in the design process remained nearly analogous to the case before computers. As information from schematic design models was exported to standard CAD file formats, the time consuming and error prone process in the transition to detailed phases of design resulted in a clear disconnection between schematic and detailed design models. During this transition, some building information and design intent that is captured in the schematic phases is lost in later phases. This presented challenges for the future of CAD tools, especially when design models and drawings were modified and synchronized among design teams from multiple disciplines.

Introducing BIM began to impact the way architects approach their designs. Machine-readable application in BIM do not just focus on geometry or complexity of shape, but more on the richness of information which can be computationally embedded in the design. Concerns became no longer how to present an idea using catchy hand-drafted or computer-drafted perspectives. More concern was about the amount of completeness of embedded knowledge in a design and the degree of precision in representing every detail in the design beforehand. BIM incorporates parametric modeling as a powerful tool for visualization and analysis, where architects define parameters and rule-based constraints to generate multiple design variations that can then be modified and evaluated (Aish and Woodbury, 2005; Anderl and Mendgen, 1996). BIM tools extend to the construction and fabrication industry, so that design is no longer separate as a process from implementation. BIM has also been increasingly used in the early concept design phase to explore different ideas and alternatives (Khemlani, 2006).

The evaluation of designs in BIM becomes judged not according to which 3D views are captured, what skill is used or what kind of representational technique is implemented, but rather on the full and complete representation of every element in the building. A full performance simulation and analysis of any building can be performed using BIM throughout the process in a more frequent and less time consuming fashion, with design modifications taken into account. The simultaneous coordination among different stakeholders is claimed to reduce costly revisions and errors, while updating the required documentation at any phase in the process. The level of validation and analysis provided by BIM capabilities opens a paradigm for architectural firms that is radically different from the drafting paradigm and allows for a more comprehensive and informative exploration of design ideas and alternatives. The advantage is that this validation process can commence at early design phases, where many parameters are still undecided. More importantly, designers can work between conceptual phases and detailed phases with no disconnection or separation, while maintaining design intent.

2.1.3 Interoperability and Interdisciplinarity in BIM

Collaboration in the AEC industry typically involves the communication and coordination between multiple professionals and specialists, including architects and engineers from different disciplines in order to execute a certain project. In the literature, there are different ways to describe an activity where multiple disciplines are involved. In the AEC industry, challenges to interdisciplinarity traditionally emerged due to specialization, where each discipline working on the same project employed its own array of practices, concepts, methods and tools. Workflows and tools in traditional CAD practices represented only a replacement of the existing trend, which focused on the exchange of drawings to describe design intent. In terms of collaboration, architects and engineers rarely relied on using each other's work directly. Only basic information from CAD drawings was exchanged, and this information was used for reference only.

With the introduction of BIM to the industry, new methods and processes were developed that might be affecting the nature of interdisciplinary collaboration. Integrated project delivery (AIA California Council, 2007) emerged as one of these methods. The rhetoric around this method is that it does affect the nature of interdisciplinary collaboration in the industry. It aims to integrate participants, practices, systems and business structures into a process that captures the skills and feedback of all participants with the goal of maximizing efficiency throughout the project lifecycle, expanding value to the project owner, and optimizing end results. This is to be achieved through the early collective contribution of expertise from different domains. By contrast with CAD, the claim with communication in BIM-enabled practice is that it is designed to take place at the model level, where the information in a 3D BIM model becomes available and ready for exchange to all participants.

One of the main strengths that BIM advocates envision in practice is the accomplishment of effective knowledge communication in the interdisciplinary collaboration process that occurs between different AEC disciplines and participants. The premise in BIM-enabled practice is that this knowledge communication can be achieved by specifying data exchange patterns between multiple building product models. This is achieved through interoperability, which describes the need to pass data between software applications to enable the contribution of different participants and applications to building model data. Interoperability was previously based on propriety file exchange formats. This limited users to single platforms, limited the possibilities of accurate information exchange among applications, introduced a lot of ambiguity, and more importantly lacked a comprehensive representation and interpretation of design intent between different collaborators. This presented efficiency challenges, where designers would waste a lot of time to explicitly express design intent or engage in studying a large amount of past documents and drawings to understand what was done, why it was done, and how it was communicated. In this mode of communication, very difficult and tedious methods were used for the management, recording and organizing of design knowledge and intent across interdisciplinary teams in the design process.

Some early efforts towards the development of BIM were mainly concerned with a clear understanding and support of collaborative architectural design processes. These efforts directly informed the issue of sharing building models for the purpose of effective information exchange between multidisciplinary teams. Kim et al.'s (1997) ID'EST project showed how a CAD model could be mapped on to a product database using STEP technology to enable data analysis by multiple evaluation tools to test its design performance. Kalay's (1998) P3 project argued that collaboration works best when specialists adopt a "super-paradigm" to achieve a common goal for the whole project, rather than merely considering their own objectives. Eastman and Jeng's (1999) EDM-2 project aimed at maintaining multiple disciplinary views of a core building model to enable simultaneous access while still maintaining the integrity of the data. Jeng and Eastman (1999) devise a process management module within a product modeling environment to support design concurrency and collaboration, allowing for the integration, scheduling and coordination of a wide range of design activities, and increasing overall productivity and efficiency of the collaborative design process.

In order to overcome the problem of proprietary formats that exist in modeling applications of different disciplines, software vendors developed different approaches in an attempt to facilitate the exchange of data across participants. These include exchange through a *single platform*, *direct interfaces* or through a *common language* (Várkonyi, 2009). In the single platform approach, proprietary file format data exchange occurs among a suite of AEC modeling applications that are developed by one software vendor. This might be convenient for collaboration among participants using this particular suite of tools, but becomes impractical and inefficient for communication between applications from other vendors. The direct interface approach uses links between different applications, where one application uses the API (application programming interface) of the other. This also requires some effort in terms of software development and workflow organization, and is dependent on business relationships between multiple vendors. These two approaches present a challenge for architects and engineers in terms of linking their collaboration to partnering vendors that share a common family of tools. In most cases, only large AEC firms can make use of these approaches, as they comprise most of the required disciplines for project delivery in-house within the firm. The larger percentage however of architectural firms has a different structure, and requires collaboration with diverse specialists from different disciplines. Each participating discipline has preferences for a unique set of methods and tools that matches its particular needs.

The common language approach adopts an open and neutral or non-proprietary model format, known as the industry foundation classes (IFC) which was developed by the International Alliance for Interoperability (IAI), building on research in product data modeling. Such an approach supports collaboration between different participants through a kind of universal communication platform. The main advantage of a neutral IFC file is the ability to directly communicate and retrieve building model data across different applications that can import and export these generic files. By providing domain-specific model views, the IFC exchange format allows for a smooth workflow and information exchange process between the architect and participants from other AEC disciplines, as each participant can access subsets of data that are of interest to his/her discipline. This mode of information exchange was believed to generate effective methods of communicating design intent between teams of designers.

Since its development as a neutral format for data exchange, there have been several critiques in the literature of IFC and the related building modeling approach for collaboration support and interoperability. Halfawy and Froese (2002) suggested several strategies and directions for IFC development, particularly focusing on embedding more intelligence into the models. Pham and Dawson (2003) show how the transfer of information in a typical building project is a complex process, and demonstrate the need to precisely comprehend how information can be captured effectively. On the other hand, some critiques (Kalay, 1998; Lee and Gilleard, 2002; Kam and Fischer, 2004) point out the issue of management of decision-making when multiple specialists and experts are involved in the process and have conflicting design proposals. They each propose a computer-based tool to support the process.

Eastman et al. (2010) view the IFC schema as necessary but not sufficient to achieve full interoperability between BIM tools. By means of use cases and information delivery manuals (IDM), they expand the breadth and flexibility of the IFC schema and provide a well structured level of detail and well defined specification contents for each information exchange between engineering disciplines to avoid errors in translation. Aram et al. (2010) also propose a progressive method to develop IDMs using exchange models (EMs) and exchange objects (EOs) to provide the information content to be exchanged between users and BIM software applications. The BIM Collaboration Format (BCF, 2010) co-developed by Solibri and Tekla companies is an open standard that enables workflow communication between BIM-authoring tools. Using BCF, architects and AEC consultants can share aspects of the interaction that are not only model elements but extend to include messages, action items, viewpoints and snapshots of certain model components for virtual discussion. These are integrated in the BIM-authoring tool so that whoever receives the file is able to locate the sent components and see them from the same viewpoint established by the sender.

Added to the complexity of conflicting roles of experts, phases in BIM are restructured and compressed such that design is no longer separate as a process from implementation. BIM has begun to transform the way designers formulate their design ideas, especially in the early conceptual phases. This is primarily due to the concept of the virtual building and the ability to construct, simulate and test design environments before constructing them in the real world. This has led theoretically to a transformation in the structure of the conventional design process.

Studying BIM in a collaborative context thus requires exploring many factors related to data exchange and interoperability. On the one hand, building models encompass a broader range of data that can be used to infer detailed information related to the cognitive activities and processes of the different social participants involved in producing a specific model, and possibly design intent. In this context, the building model can be seen as a semantically open *design sketch* representing a growing pool of embedded design concepts shared by these participants. On the other hand, introducing and transferring the tacit knowledge of participants in the process should enrich the collaborative process. The extraction of knowledge that is not readily documented, more intuitive in nature, and based on experiences or instincts, makes it more difficult to codify and transfer among collaborators.

Seletsky (2006) points out the importance of extracting and introducing tacit knowledge to the AEC industry. Project information is often tacitly updated and elaborated in the minds of participants in the process, depending on their individual expertise. At the same time, information has to be exchanged on a frequent basis due to the large number of involved stakeholders. A more effective and rich model of collaboration in BIM-enabled practice would thus integrate and combine two kinds of knowledge: (1) the virtual embodiment of explicit knowledge pertaining to all design and construction methodologies transferred in the collaboration process, (2) the tacit knowledge of design which usually resides in the minds of architects and other AEC participants. It then becomes more crucial to study these interactions and knowledge producing mechanisms situated in real world collaborative contexts; i.e. in the workplace, and not just studying design activities taken out of context, in order to have a more clear idea of how design intent is communicated in BIM-enabled practice.

The different claims about approaches to integrated project delivery and how it facilitates the exchange of design information represent an ideal view of BIM. Whether this is practically taking place in practice or not still remains an open question. The dissertation attempts to investigate current issues in practice, the nature of those issues and how they align with prospects of integrated project delivery in order to address more effective interdisciplinarity.

2.1.4 Studying BIM in Practice

BIM-enabled design and practice is a growing area, however research in this area is in its beginnings. I present a few example studies that are have aimed at exploring BIM techniques and capabilities in practice, and how their approaches are relevant to the objectives of the study in this research. Eastman et al. (2008) introduced 10 selected case studies of projects that implemented BIM. The projects were at different stages of the facility delivery process, together covering the use of BIM across all phases, and representing a variety of building types. The studies underscored the challenges and lessons learned by applying BIM tools and processes through the experiences of teams of BIM pioneers as owners, architects, engineers, contractors, fabricators, and construction crews. These case studies mostly implemented short term interviewing or web-based data collection to provide a full and quick understanding of the main modeling, simulation and analysis tools used, data exchange patterns, challenges and lessons learned by using BIM in specific projects. This was done via a post facto evaluation of these projects, and did not involve any observation of practices in the workplace.

The results however provided useful insight into BIM capabilities and an overview of different approaches to the collaboration and communication process between different stakeholders in different design and construction phases. Each study demonstrated ways by which design teams collaboratively used the available BIM tools to obtain maximum benefit. One of the basic findings in these case studies was the fact that no single project had identified or captured all or even a large portion of the benefits that BIM potentially offers. This provides some insight about the nature of BIM-enabled practice in terms of how its many benefits are actually realized in real-world contexts. It also gives way to further investigation in the workplace regarding detailed mechanisms of how BIM is being used to achieve these benefits.

Aranda-Mena et al. (2008a) explore existing business drivers for adopting BIM by AEC consultants through five selected case study projects that involve collaboration and sharing of BIM data between two or more stakeholders. Their study focuses primarily on the challenges and benefits for architectural and engineering consultants, contractors and steel fabricators. By means of a cross case study comparative analysis and examination of a set of theoretical propositions based on interviewing and discussion, this study introduces a group of categories related to the implementation of BIM in practice, including collaboration, efficiency, design functionality, resources, alignment and others, and proposes some initiatives for each category based on the level of agreement with the study propositions. As basic findings, the study highlights the importance of the proposition that BIM improves information flow, management and sharing as one of the strongest propositions that emerged from the collected data. This study develops a business case framework for adopting BIM in practice, and describes its objectives and a set of operational, technical and business outcomes based on the results of the case studies. It does not go further in detail to describe the properties and dimensions of each of the discussed categories or the mechanisms and social interactions that occur, let alone the nature of communication of design intent that takes place between the different AEC participants in the case studies. It sets ground however for further exploration of categories of phenomena that may emerge from using BIM in practice.

The study by Tessema (2008) implements a set of descriptive and explanatory case study approaches to comparatively analyze the building design information represented in documents generated using traditional practice and BIM. This study was not based on studying designers at work, but on comparing the documentation of design knowledge produced. The objective was oriented to understanding how BIM could improve the quality of information available especially to the architect and client. The ultimate goal was to study how architect-client communication can be enhanced in schematic design phases. In the study, the researcher developed a BIM model for an existing case study project that was originally implemented using traditional CAD practices, and generated design documents off of the BIM model. By means of analysis and comparison, the researcher found that the BIM model delivered a quality of information that was higher than that produced by traditional CAD. The focus in the examined information was three main characteristics of the designed building: function, cost, and appearance. The argument then was that enhanced building design communication can occur between architects and clients using BIM.

The research by Sanguinetti et al. (2011) attempts to explore how design intent communication can be reinforced and enhanced by implementing modules for different types of analysis for building models, including energy analysis, cost estimation, spatial validation and circulation rule checking. The research aims at generating automating reviewing and reporting for building models regarding these analyses. The advantage here lies in capturing maximum design knowledge and analysis from schematic building models which contain minimal and rudimentary information, representing it and accessing it in a way that presents ongoing and informative evaluation to the designer.

More effort lies in embedding this knowledge in the authoring tools and providing more flexible data exchange patterns with other analysis tools in order to offer the designer a continuous stream of guiding benchmarks for the decision making process.

Hartmann et al. (2009) describe a project-centric research and development approach to develop and implement information systems for supporting collaborative work routines in AEC projects. This research does not focus on studying BIM per se, but takes it into account as one of the information systems that are used in the AEC industry. The methodology of the research focuses on an ethnographic observation of practitioners at work in AEC projects and understanding their requirements through small action research implementation cycles. Specific focus in this ethnographic approach to studying collaborative design is on the close relationship between technology developers, researchers and AEC practitioners. Through an iterative cycle, technology developers establish a detailed understanding about the project routines, collaborative work mechanisms of AEC practitioners, the problems they face, and the tacit knowledge they possess and use during their daily practice, and consequently develop information systems in response to their understanding. After applying those systems on AEC projects, researchers then study how practitioners change their project routines accordingly and identify those routines, and the cycle continues.

One of the main findings of this research is the suitability of the ethnographic approach, and in particular the ethnographic-action method, for the development and implementation of information systems. It further shows that this approach allowed for identifying specific problems in the AEC industry, and provided an aid for adapting information systems through the close collaboration between researchers and AEC practitioners. These findings do not only provide a basis for supporting the use of ethnography as a method in studying BIM in the context of AEC interdisciplinary collaboration, but also suggest ways of using that method for the potential development of systems that enhance current functionality and structure of the BIM-enabled process.

2.2 Design Intent

The issue of design intent evolved as early as the first century BC, when Vitruvius discussed the intrinsic value in the use of plans, elevations, and perspectives to communicate design intent. Later in 1452, Alberti the early Renaissance architect suggested that the essence of design lay in the thinking process related to communicate the design to building stakeholders through lines on paper. The goal was to distinguish the intellectual task of architectural design from the craft of construction, and enable all stakeholders to share various views and tasks in the design process to effectively execute the design for the client (Morgan, 1960).

2.2.1 Definitions and Interpretations

Many definitions exist for the term "design intent". These definitions, which deal primarily with reasoning and design decisions, are mainly consistent across the spectrum of engineering design disciplines, from mechanical design and architecture-engineering-construction (AEC) to software and user-interface design (Regli et al., 2000). Researchers in multiple engineering disciplines have defined design intent as the reasoning and rationale behind why a product or some part of it was designed in a certain way (Fowler, 1996; Lee and Lai, 1991; Horvath and Rudas, 2003; Henderson, 1993; Pena-Mora et al., 1993). Conklin and Yakemovic (1991) slightly extend this definition to include the reasoning behind why an artifact is structured the way it is and has the behavior it does.

Another closely related view of design intent involves the justification of design decisions. Conklin and Yakemovic (1991) represent it as the path of decision and chosen alternatives that join an initial state to the final state. This is further supported by Brissaud et al. (2003) who represent design intent as design alternatives, decision-making and design constraints. Henderson (1993) distinguishes intent from functionality in light of this view, where functionality describes only what the design does. Wang and Mills (2000) extend this definition to address both the generic view of design intent and the domain-specific view from disciplines of engineering and architecture. They describe intent as the justification of design decisions in terms of selecting physical values for structure variables to satisfy constraints. Horvath and Rudas (2003) describe the emergence of domain-specific knowledge as a basic characteristic of design intent. The significance of design intent has been discussed widely. Ishino and Jin (2002) point out the importance of explicitly representing design intent in realizing coherent integration of design solutions and communication of design knowledge. Hounsell and Case (1997) also mention the need for design intent in validation systems that are capable of reasoning about the semantics in a particular design.

In terms of industry, Pena-Mora et al. (1993) mention several advantages that AEC industries can gain through the explicit representation of design intent. One of these advantages is better project quality and intelligent use of knowledge and resources, as project intents are represented explicitly in building models and become readily accessible for review. Another important advantage is enhanced productivity, represented in the capability to store and recall reasons and justifications behind the decision making process across different phases of the design, which would otherwise be lost or require continuous and tedious definition.

While design intent concepts are discussed in many disciplines and contexts, there are many interpretations of what it really means. These interpretations mainly deal with design intent as falling into one of two categories: design intent as (1) a historical record of analyses and decisions that led to the choice of a specific product or feature (Lee and Lai, 1991), or (2) the sum of the features of a product (functional, geometric, constraints, etc.) and their properties. The work of Horvath and Rudas (2003) also addresses issues from both categories. They classify design intent into three levels according to application, relationship and representation. They identify attributes for each level, including the type of intent, status of intent and status of decision maker. Some of these attributes, like type of intent, are further decomposed into characteristics such as possible alternatives, compatibility, application type, and intended strategy. At the same time, they address design intent as the intellectual arrangement of features and dimensions of a certain design. They argue that a reasonable segment of design intent can be inferred if the relationships and dimensional variables of the design features are known.

Hounsell and Case (1997) suggest that product features are carriers of a designer's intent, and therefore promote and augment the notion of feature-based modeling systems. In their argument, they interpret design intent as the sum of volumetric, morphological, semantic, functional, and validation features, in addition to the relationships between these features or certain elements of the features. Their system FRIEND (Feature-based Reasoning system for Intent-driven ENgineering Design) uses design intent to describe the semantics of a feature. Nielsen et al. (1991) use an intent-driven knowledge based method to represent the design process. In this design-by-features approach, features describe not only form but also intentions of designers regarding geometric relationships. Geometric intent is modeled as restraints on geometric attributes of the designed form. Rosenman and Gero (1998, 1999), Gero and Kannengiesser (2003) and Fenves et al. (2003) introduce another interpretation of design intent, which involves the sum of the function, behavior and structure of the design product. The proposed frameworks in their research all use those three variables linked by processes.

While different interpretations of design intent exist in the literature, there are some common and basic concepts that hold within these interpretations (Iyer and Mills, 2006) such as the fact that design intent acts as a record of processes and analyses and a justification for design decisions, that it is specific to the domain, application and problem context, that it evolves throughout the development lifecycle, and that it extends from implying just geometry to describe design space and other variables such as function and behavior.

The term "design intent" yet encompasses multiple and broad areas of research for the AEC industry. It can mean the intent of the architects' or consultants' drawings, the documentation of their design decisions, the specifications related to the drawings, the intended functionality and operation of the design process, the goals and expectations of multiple AEC practitioners, or the programmatic requirements implied by the client. To narrow down the scope of what is meant by design intent in the dissertation study, section 2.2.2 describes some of the related social and cognitive dimensions in the context of collaborative practice.

2.2.2 Cognitive and Social Dimensions

Research in cognitive science, social sciences and cognitive psychology has identified further dimensions to the area of design intent, focusing on cognitive and social dimensions. Areas of research included information processing, decision making, searching the design space, design reflection, complex design problems, collaborative design, communication of design knowledge, and maintaining conceptual integrity. The limitations of human information processing capacity have had an impact, both at the cognitive and social level, on any system concerned with the capture and representation of design intent. Simon (1996) describes these limitations in terms of bounded rationality, where humans choose satisfactory solutions based on available information rather than optimal solutions that comprehensively consider all design issues, conditions, constraints and alternatives. By providing more information at the disposal of both the designer and other participants in the process, design rationale systems attempt to overcome these cognitive processing limitations.

At the cognitive level, designers could have a better chance to search for alternatives, and evaluate and reflect on their decisions if design intent is captured and recorded along the process. More time could be spent on thinking about the right issues rather than reflecting uselessly on each individual aspect of the design. Designers could be able to identify which concepts were deliberated throughout their thought process, in addition to taking into consideration issues and consequences that may have been originally unintended (Tenner, 1996). This introduces a benefit for designers in their exhaustive search of the design space for missing pieces of information with the aim of reducing the chance of unanticipated effects of design decisions. One of the early research efforts that focus on information processing in design includes the case studies by Krauss and Myer (1970). Several studies explore the role of drawings in inferring and interpreting the designer's intentions (Eastman, 1970; Do et al., 2002). Akin and Özkaya (2002) describe an approach to manage ill structured requirement specification throughout design phases and iterations to reduce design errors.

Recent efforts, such as the Design Intent Tool (Wilkinson, 1999; Stum, 2002; LBNL, 2011) provide structured approaches to document design intent, ensure the alignment of perspectives of multiple stakeholders, and track design decisions and benchmark specific performance indicators throughout the design process. In such collaborative contexts, both cognitive and social dimensions of design intent are addressed. Design rationale systems were generally intended to support collaboration, where designers with different goals and viewpoints come together in order to collectively understand and solve a design problem. Recording design intent is described in the literature to serve as a communication tool between different participants in the design process. As more participants are involved, more and more design ideas are considered. Although this adds much more complexity to the process in terms of integrating multiple viewpoints and updating team members on design issues, keeping track of intent aims at alleviating this complexity and sustaining conceptual integrity within a design project (Brooks, 1995). This happens both at the level of multiple participants working on the same task, and at the level of communicating design issues and concerns to future designers who may have to work with a similar task. One of the challenges in collaborative design in practice, known as groupthink (Janus, 1972), involves arriving at poor solutions due to following poor processes. This phenomenon was observed within design teams working on complex projects with very firm deadlines.

As a result, teams would shift their attention to somewhat unimportant issues that are not relevant to the design decision making process.

Recording and representing design intent should enable the explicit description of the communication process, or of the *argumentative process*, among designers in a way that leads to more effective decision making. The advantages of structuring, exposing and visualizing the argumentative process that takes place between social participants have been discussed widely by several researchers in architectural design and different disciplines. These include the ability to represent the viewpoints of multiple stakeholders (Sjoberg and Timpka, 1995), the importance of informed decision making in the context of complex design projects involving multiple social entities with different interests and perspectives (Fischer et al., 1991; Tweed, 1994; Tweed, 1997), the construction of cumulative design knowledge by means of continuous use and reuse of rationale (Carroll and Rosson, 1991), establishing consistency in the decision making process (Lee, 1990), the negotiation of trade-offs between different disciplines (Bellotti et al., 1995), elucidating vague requirements and recording the rationale behind their progression (Potts et al., 1994), and communication of design intent to other participants or designers throughout the process of collaboration (McKerlie and MacLean, 1994). Van Eemeren and Grootendorst (2004) view argumentation as a way of resolving differences in perspective or opinion based on four key concepts: *externalization*, where external representations determine positions in an argument; *functionalization*, where the main function of argumentation is the resolution of conflicts; *socialization*, where arguments and positions are seen as part of a social context rather than an individual one; and *dialectification*, where argumentation is considered only suitable when people are able to use arguments that help them argue against other people.

Research in architectural design collaboration has previously focused on developing systems particularly in the context of computer supported collaborative work (CSCW) (Olson et al., 1992), to address communication media, different types of synchronous and asynchronous collaboration, social organization, and content and data exchange. More recently, other issues were identified that were related to socio-cognitive aspects of communication. Cheng (2003) describes two approaches that researchers of design collaboration tend to address: (1) data organization, information flow, and what software applications offer to interdisciplinary teams, and (2) group thinking and working collectively with digital media. This latter social science-driven approach presented an important step for developing tailored computer software and data structures for collaboration support. Issues that were salient to this approach included understanding group interaction, including data exchange, observing participant interaction with digital media, identifying design tasks, and encoding social processes to develop effective communication tools (Cheng, 2003; Kvan, 2000). These tools were generally created to enhance teamwork communication and to allow for better access to design information.

The design process has been viewed by different researchers as a social activity where the role of the architect or engineer is only understood when described in relation to other participants like the builder, fabricator, client or user. Bucciarelli (1988) describes the process as one that only exists in a collective fashion and is difficult for just one individual to describe or fully define. Lawson (1994) describes the process in the context of a socio-cognitive practice as a constant negotiation of meaning both between and within individuals, implying that designers can exchange and negotiate meaning with other participants and can also have internal reflexive conversations. Cross and Cross (1995) view team work in design as a social process, where the social process of design interacts significantly with the technical and cognitive processes of design, and where the roles and relationships within and across teams cannot be excluded when team design activity is analyzed. They describe many aspects of team design activity as being influenced by social process factors such as roles and relationships within teams, planning of the design process and team actions relative to that plan, gathering and sharing of information, ways of analyzing and understanding the design problem, ways of developing and adopting design concepts, and resolution and avoidance of conflicts.

There is a wide debate among the design collaboration research community regarding the role of collaborative interaction in design. Some researchers see collaboration as a positive aid to the design process, where new ways emerge for understanding design issues and problem space representations by virtue of the distribution of expertise among collaborators. This approach expands Schön's (1983) "reflection-in-action" to a wider concept that is enlightened by interactions with social participants; that is "collective reflection-in-action" (Craig and Zimring, 2002, Dunbar, 1995). In this approach, the individual thought process, together with all its problem space definitions, actions and justifications, becomes open to the interpretation and validation of other social participants. Novel and originally unintended *readings* of design problems and contexts start to emerge, leading to a collective effort that may be difficult to achieve without such collaboration. Other researchers view collaboration as obstructing the search process for suitable design solutions, as *competing* problem space representations between collaborators lead to *conflicts* without appropriate shared resources for resolution (Goel, 1995).

From the aforementioned, the dissertation focuses on a subset of design intent that involves the extent to which the initial individual and collective goals and information needs of different participants in a given project are captured and conveyed effectively across participants and teams throughout the design process. The dissertation attempts to investigate the extent to which BIM workflows and processes, as seen in the interaction between AEC design teams, support or hinder the collaborative process of communicating design information across and within different communities of practice, and how they address different interpretations or readings of the design problem space and the potential conflicting interests between social participants sharing the BIM model.

2.2.3 Representing Design Intent in BIM

Design intent is one of the areas of discrepancy between CAD and BIM. CAD tools are traditionally capable of capturing geometric aspects of design intent, but offer limited assistance when it comes to query the rationale behind design decisions for designing or redesigning purposes or capture aspects related to design alternatives, design procedures and functionality (Henderson, 1993; Hounsell and Case, 1997). Designers conventionally used CAD tools to generate designs that satisfied some intent, but this intent is not actually represented within the system. The modeling process in CAD tools involves defining instances of a specific building element, such as a wall, slab, or roof. These are either built from scratch or using a library of object classes defined according to some geometric variables. The user must position the element instance in the model, define values for the given variables and define other non-geometrical attributes such as material and color.

If the designer wishes to perform any modification on any of the defined instances, he/she would have to manually edit the values, location, and relations for that instance, and then deal with the consequences that this modification brings to other elements, and sometimes the whole model. If one aspect of the model is modified, multiple changes often have to be done to readjust to the desired situation or to the implicit design rules which represent in this case the original intent of the designer. This occurs because the system does not keep track of rules. As they are not defined beforehand, the user has to decide whether and when these rules are broken and what should be done in all possible objects in the model to adjust that one breaking of the rule. In other words, while the geometry is explicit the rules are implicit, where the user has to keep track of the rules instead of the system which cannot. The situation is believed to be different in practice that uses BIM. Patterns of collaborative work are fundamentally different, where multiple designers and participants can work concurrently early on in the process to make design alterations and achieve enhanced building quality and functionality based on an efficient model of data exchange and design intent communication.

The full effects of proposed design modifications are thought to be visualized by different stakeholders at early phases and tracked along design progress, along with a realistic and accurate evaluation of cost and scheduling. This allows for a considerable reduction in errors, omissions and requests for information, as the building model itself contains the necessary information and can detect and resolve conflicts among different fieldwork participants. One of the concepts that facilitate these capabilities is parametric modeling, where rules are explicitly defined and the geometry is implicit. The parametric model is defined by rules, parameters and constraints that define elements and aspects of the building and their relationships to each other. A basic component of the design process becomes the creation and modification of these relationships.

Parametric tools in general contain base parametric objects such as walls, columns, roofs, slabs, doors, beams, in addition to supporting the creation of custom parametric objects. The modification of an object, rule or constraint has implications on the rest of the model objects that are affected by this change. This provides the capability of automatic updating of an object or the whole model in accordance with changes made in one object based on the parametric relations between them. A curtain wall for example should hold some rules and relations with the surrounding slabs, walls and beams which in turn derive their dimensions and extension limits from the location of the wall. If the curtain wall is moved horizontally in any direction, the parametric relations will update all these objects accordingly. Parameters, relations and constraints in this case capture most of the designer's intent which describes what the designer originally desired in terms of the functional, structural and behavioral aspects of the wall.

This automatic update relieves the user from having to manually modify all implicitly related objects and guarantees a level of consistency and integration in model updates and transfer of edits without being troubled about maintaining this consistency and integration tediously. This also presents an important functionality for multiple designers working on the different aspects of the same building model.

There are two main methods by which this automatic update occurs in the structure of parametric modeling tools: constructive and variational modeling. In constructive modeling, the process of sequencing of modeling operations and data transfer is the main concern. This deals with the issue of modeling history and tracking the steps followed to generate the model. This is represented by a directed graph, where nodes represent geometric elements and edges represent modeling operations. Variational modeling is concerned more with rebuilding and solving parametric relations and equations once the user introduces any changes at any modeling stage.

The determination of rules and parameters occurs through defining classes of objects or *families* that use these rules to specify the relations that all objects under a certain class should maintain with other objects or any other requirements. Object parameters can be user defined or can be set to follow another object parameter. For example, the dimensions of a column can be derived from the number of floors of the building. A family also supports the generation of instances that can have changing values according to their context. A column family for example can have multiple column instances with different radii according to their location in the building or different heights according to the floor height to which they belong.

Parameters can extend to include not only physical or geometrical features, but also environmental features or other properties such as occupancy level. The thickness of a slab or the dimensions of a stair for instance can be derived from the projected occupancy level for a certain space. This also applies to the form of a building for example whose parameters can be derived from environmental conditions such as amount of daylight entering the building. Constraints could also be specified to objects by representing mathematical relations between their parameters. They can also be represented symbolically using relationships such as parallelism, horizontality, verticality, coincidence or distance constraints. Warnings could be issued if certain conditions for constraints are not fulfilled. For instance, a constraint could be specified for the height of a space such that the user gets a warning if a height value that exceeds the limit is used.

Logical relationships can also be established between objects by means of parameters and relations such that possible and impossible cases can be realized. These include cases like containment of a door within a wall, the attachment of a beam to a column, or not accepting a wall dimension that holds a number of windows that in total exceed its dimension, etc. These relationships preserve the integrity of model data and reduce to a great extent any odd associations.

Object properties could also be easily modified and updated. By changing the material property of an object, not only does the attribute get modified, but also the related geometric definitions, dimensions and properties of that object. Changing the material of a floor slab for example from one composite material to another implies also changing its thickness for dimensioning purposes, its weight for building load calculation, material quantities for cost estimation purposes, and so on.

Another important feature of BIM is the interoperability across different tools, including tools for cost estimation, construction scheduling, facility management and others. In this context, multi-dimensional (nD) capabilities can be illustrated. 4D capabilities for example refer to virtual building in a time-lapsed manner such that constructability and scheduling issues can be addressed clearly. Other aspects beyond time such as labor can be simulated to predict and visualize different workflow patterns through external scheduling databases. 5D refers to the ability of linking models to external cost databases that can give owners a better understanding of how projects perform according to the allotted budget. Other capabilities envisioned in BIM-enabled practice include 6D which involves supply-chain integration and 7D which is concerned with operational lifecycle analysis.

Most of the previous capabilities present enhancements in data exchange, interoperability and design intent communication that are primarily claimed by BIM advocates and software tool vendors. The dissertation does not fully deny these capabilities, but calls for studying in depth how they come to realization in the workplace, and in architectural practice in particular to have a more precise account of the affordances and limitations of BIM in communicating design intent. My proposed research aims at capturing the interactions, collaboration patterns and knowledge transfer mechanisms that take place in the BIM-enabled process to understand how design intent communication is addressed in practice. Methods of analysis such as short-term empirical studies, case studies, surveys, questionnaires or protocol analysis would provide some insight but would lack the long-term and robust observation of interactions and mechanisms within groupwork environments. In order to extract enough information about the processes that take place in BIM, I intend to conduct an ethnographic study of a collaborative environment within the AEC industry. In the next chapter, I describe in detail the methods and scope of the study and how data from the study will be analyzed.

CHAPTER 3

METHODS OF STUDY

This chapter introduces the main methods of study employed in this research. The research adopts ethnographic field observation and interviewing as a strategic qualitative methodology to capture the types of interaction that take place between the different participants in the context of BIM-enabled practice, as well as grounded theory coding as a basis for analytic induction. The research also adopts personas as an additional method of analysis. As the unit of theoretical analysis and inquiry, personas are seen through interactions with other participants and artifacts in the specific context of practice. The chapter provides an overview of ethnographic research, why it is adopted in this study, and its precedents in the architectural profession. Data collection procedures, including field observation and interviewing, are discussed, as well as the process of transcription, coding, analysis, and verification of the qualitative data from the study.

3.1 Data Collection and Analysis

The process of exploring design behavior in general has usually taken the form of interviews, retrospective reports, concurrent reports, teaching, and introspection, which all contribute to the empirical understanding of the design process (Lloyd et al., 1995). Studying design as a process, however, and as a collective activity and conversation that occurs in a socio-cognitive context and that involves continuous negotiation, argumentation and construction of meaning, requires a different kind of observation and analysis technique. Protocol studies (Ericsson and Simon, 1993) have attempted to observe activities of individual designers and analyze cognitive behavior, in addition to analyzing design activity among teams working in collaboration (Cross and Cross, 1995). These studies have proved effective to some extent but focus primarily on verballygoverned behavior and do not take into account day-to-day social and cognitive practices of subjects. The dissertation employs qualitative methods and analysis to address the main inquiry. Traditionally, qualitative methods were introduced in the social sciences to develop comprehensive understanding of human behavior. Other disciplines started to use qualitative methods significantly during the 1970's and 1980's such as psychology, information studies, education studies, communication studies, and many others. This was accompanied by widespread publications of studies, articles and dissertations related to qualitative research methods, and followed by other publications in the 1980's and 1990's that embraced a more multidisciplinary focus rather than the conventional research rooted in sociology, anthropology and philosophy (Denzin and Lincoln, 2005).

In spite of the growing inclination to adopt qualitative research as a method of inquiry, there have been sporadic challenges and doubts regarding the legitimacy of this type of research in terms of credibility and reliability. Qualitative description is often viewed as relying more on narrative rather than tangible results, thus raising the level of ambiguity and debate, and making it harder to accept with respect to replication and generalization. However, through its open-endedness and flexibility, it has the advantage of producing meaningful information that is both rich and explanatory in nature, where a "thick description" explains the reason behind human actions with as much detail as possible (Geertz, 1973).

The context of inquiry in the dissertation research involves dynamic contributions from multiple participants with diverse backgrounds and areas of expertise, who use different concepts, tools, methods and resources. These dynamic interactions contribute to a form of interdisciplinarity where the "melding of knowledge and practices from more than one discipline occurs continually, and significantly new ways of thinking and working are emerging" (Nersessian, 2006). This combination of resources is not only of academic disciplines, but also of experience, interests, motivations and goals that may not necessarily align with those of a "typical" domain. (S1) for example comes with a background in both mechanical and structural engineering. The intern (A4) for example comes with a teaching experience that mostly affects her approach to design during the project.

Other factors yet come into play, such as new work experiences, new social interactions, temporary or permanent departure of participants and arrival of others to aid with workload, including engineers, architects, project managers, interns, and even the client, transition to new systems, organizational structures, technologies and computational tools, exchange of tasks and assigned roles, adjustments to project programmatic requirements, and many others. These factors contribute to what is known as evolving systems (Knorr Cetina, 1999) which undergo continual transformation to respond to the activities performed by their participants, affecting their social structure and knowledge mechanisms and resources.

In order to provide a thick description that takes into account the context of inquiry with all its dynamic interactions and all the aforementioned factors, it is necessary to state the employed methods but first to identify a theoretical unit of inquiry and analysis (Denzin, 1971). This basic unit of naturalistic inquiry encompasses the analytic focal point of the research and determines the specific methods used. In this research, the context of inquiry comprises two main modes of interaction: 1) a process of exchanging data among design teams and participants by means of a shared BIM model, and 2) a process of exchanging issues, views and arguments among design teams and participants by means of a shared ill-structured problem that involves socio-cognitive interaction. To capture these two modes of interaction in BIM-enabled practice, the dissertation adopts *ethnographic field observation* and *interviewing* as a strategic data collection methodology. The unit of inquiry in this case is the participant, or the *persona*, seen through interactions with other participants and with artifacts, including digital and physical representations, in the context of practice involving disciplinary participants. The dissertation study therefore relies on two main methods:

1. Ethnographic observation, including field notes, open and semi-structured interviewing, and attending design meetings: the purpose of this method was to establish a deep understanding of the affordances and limitations of building information modeling in AEC practices through the close observation of day-to-day practices, and
2. Personas: the purpose of this method is to build on the observation findings and on existing BIM systems to propose recommendations that address both technology development and social interactions in communities of practice.

Although these two methods stem from two very different fields of research (anthropology and sociology versus human-computer interaction), they are used in conjunction as complementary methods; to understand the context of BIM-enabled practice on the one hand and to address advancements in technology development on the other. These two methods will be discussed in detail in along the course of this chapter.

In parallel to the data collection, the research uses grounded theory coding as a basis for analytic induction through the constant comparison and examination of results (Strauss and Corbin, 1998), with the purpose of arriving at a group of emergent phenomena pertaining to the basic research inquiry. Although audio and video material from interviews and meeting sessions has been collected for this study, the focus in the analysis and coding is on text from these interviews, meetings and field notes. Although this material could have been more informative in terms of conveying sophisticated levels of interaction, the primary concern here is communication of design knowledge and information. The assumption is that open and semi-structured interviews, although not delving into every single detail, would expose the social and cognitive practices in the context of study. The interview, which is furthermore situated in the workplace, is also supplemented by notes from field observation and other sources such as drawings, artifacts and digital files, that all add to the understanding of the context.

The data from interviews and meetings was collected in this study over the course of 8 months, which represents the duration of the SG project starting from the early programming phase, going through schematic design (SD), design development (DD), and ending with the construction documents (CD) phase. The author became a participant observer of most of the day-to-day practices in each of the firms (architectural, structural, MEP, AV, and civil and landscape), especially the architectural firm where most of the decision making took place and where design meetings sessions were held with the consultants.

One of the problems that usually arise when dealing with ethnographic interview data is that what participants describe or what they say they do may not accurately reflect what actually takes place in practice, or may not provide an adequate description of reality according to Geertz (1973). There are often contradictions between what participants think their motivations and belief systems are for example and what their actions turn out to be in reality. This required that the author – also the ethnographer in this case – be better able to describe the practices than the actual participants by means of direct observation, testing and triangulation of data by means of artifacts, literature, or other participants. It was hard to totally overcome this problem however, but the process of identifying some of the emergent phenomena in the study was supplemented using direct observation and examining project data. Sections 3.1.1 and 3.1.2 present an overview of ethnographic observation and why it was specifically used as a data collection method. Personas will be discussed as an additional method of analysis in section 3.5.

3.1.1 Why Ethnography?

To be able to understand the suitability of ethnographic observation for the purpose of this study, it is first necessary to define what ethnography is. According to Fischer & Finkelstein (1991), ethnography is a qualitative method for collecting rich and complex social data. Qualitative research in general covers a wide range of methods, from purely open ended to highly structured methods. Ethnography primarily relies on field observation to study organizations, cultures and groups of people in action. Some ethnographic practices have also relied on semi-structured interviewing.

The data collected in an ethnographic observation are not theory-driven, but rather work through a bottom-up analysis, where analytic induction is used together with continuous comparison through the inspection and triangulation of the different sources of data that the ethnographer comes across (Eisenhardt, 1989; Miles and Huberman, 1994). The analysis of all these types of data is conducted through grounded coding in order to build theory.

Ethnography was first developed under the discipline of social anthropology as an attempt to observe radically varied cultures. It was later adopted under the discipline of sociology and was used to study organizations and groups of people in action. Other properties such as skill, technical competence and professional expertise began to be under study in ethnographic observations and not just cultural practices. These practices were seen as residing in social communities and organizations and not just as a commodity for individuals (Coyne and Snodgrass, 1995). More recently, ethnography has been adopted by cognitive anthropology for studying complex socio-cognitive systems, where specific attention was directed to studying the coordination between expert science and engineering teams in decision making processes (Hutchins, 1995).

One of the main differences between ethnography and other qualitative research methods is that ethnographers try to understand how members of a certain culture act, think, feel, interpret experiences and create social behavior in their everyday practices (Spradley, 1979). Reaching this level of understanding in AEC practices requires starting from the collected data about the socio-cognitive context of designing and not through a forced theory or preconception of the mechanisms in the studied culture. This implies a close observation of the practices of design team members during their daily work, learning the language they speak and how they produce, exchange and communicate knowledge in their routines, and studying what artifacts, computational tools and applications they use in such a process. Data thus need to be collected from multiple sources of observation such as interviews, passive observations, and participant observations, in addition to supporting documents such as project meeting minutes or reports (Yin, 2003).

To capture the essence of disciplinary collaboration and constant negotiation in BIM-enabled design practice, it might not be enough to evaluate the final design product or perform a quick survey or questionnaire regarding the nature of this collaboration. The collected data in such cases may not provide a comprehensive account of the underlying issues such as the collective thinking process, decision making, social organization, cognitive processes, learning curve, meaning making, reasoning, tacit knowledge, negotiation and argumentation among designers, the role of expertise, and many other issues. To address such issues and understand them fully, it is important to study in detail the day-to-day practices among teams of designers and observe closely the associated socio-cognitive processes in their interaction. This relies on the ability to systematically record, report, organize, analyze and explain the mechanisms of this socio-cognitive system. The goal of this observation is not to test a specific hypothesis per se, but to explore those different processes and mechanisms and bring insight about them to the reader through a convincing description.

This description is not just a narrative but a *thick description* of human behavior (Geertz, 1973). This description explains not only the behavior but also includes the context of practices and discourse within the society in a way that renders that behavior useful and meaningful to an outsider. Current research in BIM and design intent communication lack this kind of thick description that provides an account of the interactions and mechanisms taking place in the social context of collaborative design between disciplinary teams. Throughout this chapter, I explain how the proposed description is enacted by means of the personas identified in the study and their different interactions. First, I introduce some of the precedents in the field of ethnographic research.

3.1.2 Precedents in Ethnographic Research

Studying architectural design practices emerged from the work of anthropologists and sociologists which provided a framework for studying any group of professionals in a particular type of practice, including architects, in what they identify as a *culture of work*. A culture of work describes a group of social norms that control the behavior of any individual working in that practice.

Cultures of work in a discipline like architecture for example could then be studied according to anthropological and sociological tools similar to those used to study cultures and groups of people in traditional anthropological research. These tools, which include *field observation* and *interviewing*, would aid ethnographers in understanding the properties of members of the culture under study. Below I present an overview of some precedents of ethnographic observation in two areas: architectural practice, and technology development.

3.1.2.1 Precedents in the Architectural Profession

Studying architectural design practices has been traditionally divided between two camps of methodological approaches that introduce a lot of controversy within disciplines of anthropology and sociology concerning the applicability of empirical methods to the social sciences: the objectivist approach and the subjectivist approach. The objectivist approach suggests that human behavior can be recorded and measured quantitatively with replicable results. The subjectivist approach proposes that qualitative narratives provide more information about people's behavior and personal realities. Ethnographic observation and fieldwork belong to the latter approach (figure 3.1).

Ethnographers studying architectural practices have usually followed methods similar to the work of anthropologists and sociologists with no special accommodations for discrepancies in the profession. Researchers traditionally spent time in architectural firms observing the physical context and the social interactions among design team members, depending mostly on field observation and ethnography rather than theoretical studies.

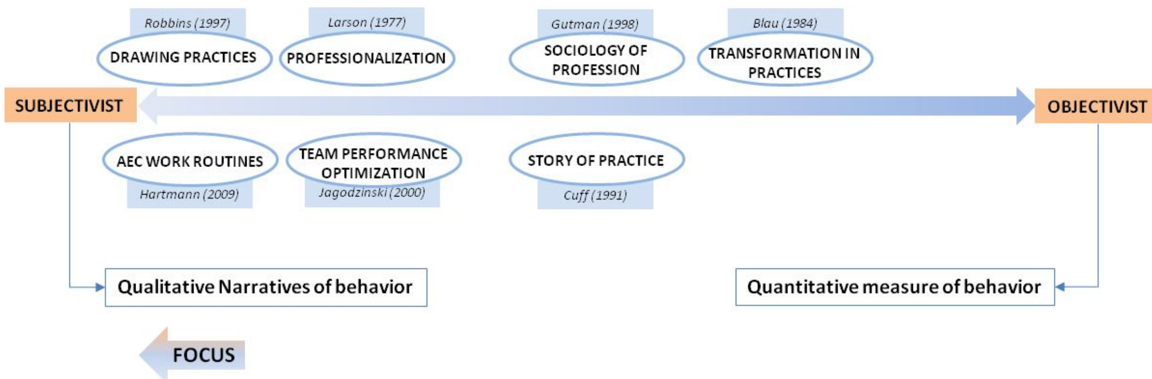

Figure 3.1. Focus of ethnographic observation and fieldwork in the study along the subjectivist-objectivist methodological approach

Some early examples of ethnographic observation work studying the architectural profession include Larson's (1977) study of the professionalization process, Blau's (1984) study on the transformation in architectural practices over time which were taken five years apart and implemented interviews with 400 architects, and Robbins' (1997) study on drawing practices of architects. Although these studies referred to some of the work settings in the profession, the interviews were not informed by personal experience and were disjoint from everyday routines. The work by Blau (1984) examined the correlations between the attitudes of architects and the success or failure of their firms by using statistical methods such as analysis of variance. This placed these types of studies in classical sociology research instead of applied work practice research.

Other studies were based upon the work of sociologically minded members within the architectural community. These studies, including the work of Martin (1996), Gutman

(1988) and Cuff (1991), shaped the fundamentals of understanding design as a profession. They employed qualitative methods to report on personal experience working with the architects they observe as an alternative fieldwork. Not all research involving design as a profession however has firmly or neatly belonged to one of the extreme ends of the objectivity-subjectivity spectrum. Some of the studies adopt a rather hybrid approach. The work by Gutman (1988) and Martin (1996) uses sociological methods that emerge from personal experience, but at the same time other data such as professional membership registers is used to supplement this experience.

Cuff's (1991) work and interviews also tend to make some claims at objectivity more than being oriented toward participant observation although her work does not involve quantitative analysis or surveys. At the same time, although she does not study technology development in her studies, she uses the ethnographic approach preferred by applied work practice research which aims at observing a culture to identify opportunities for integrating technology.

3.1.2.2 Precedents in Technology Development

Some considerable work in ethnography and work practice studies has been done in the field of technology development. This work primarily focuses on fields of human computer interaction (HCI), information systems and engineering design. Many HCI curricula began taking into account ethnographic methods of inquiry for conducting work practice studies (Shneiderman, 1998; Dix et al., 1998).

Most of the activities involved in applied work practice are concerned with either understanding the physical artifacts used in everyday routines or studying the work flow and organizational structure between different team members. The outcome of these kinds of studies usually helps designers to have an informed decision about the design of the user interface of a system by avoiding certain work flow conflicts or arriving at a common vocabulary for the system design.

Hartmann et al. (2009) describe a study that aims at developing information systems for AEC design team members. They show that ethnography, and especially ethnographic-action research, is well suited to formulate work routines that AEC team members face during their day-to-day work, to understand these routines, and to adjust information systems to these routines throughout the life-time of a project and across different projects. Jagodzinski et al. (2000) describe a set of studies that involve implementing ethnographic approaches to studying engineering design and developing computational support. These focus mainly on engineering rather than architecture, with a special interest in team performance optimization. One of the related architectural examples is Emmitt's (2001) study which describes his experience while observing design teams in the process of choosing building finishing materials.

The dissertation implements ethnographic observation in a way that addresses both architecture as a profession and technology development. The observation study explores issues related to communication of design intent with the purpose of studying (1) BIM-enabled architectural practice in the context of AEC collaboration, focusing on patterns of argumentation and negotiation of meaning, and (2) computational development, in terms of identifying patterns of data exchange among design teams and participants within and across disciplines.

3.2 Data Collection Procedures

The time frame for this study was approximately 8 months, starting from the phase of programmatic requirements to the delivery of construction documents. The time spent in the firms together amounts to about 140 hours, including about 30 hours of interviews and 20 hours of team and consultant meetings. The data collected was in the form of general field note observations, audiotaped interviews and audio/video taped group meetings. A total of 25 interviews were fully transcribed and analyzed.

Early concept design phases within the project were the starting point for this study. This is where it was anticipated that in a BIM-enabled setting most of the decision making and design thinking processes would occur collaboratively, and where disciplinary teams would come together to develop the basic components and ideas for the shared building model. Observing this phase allowed for the exploration of the interactions and negotiations that occurred early on in the process. Extending this however to observe later phases also allowed for tracking the communication patterns of argumentation and negotiation within and across teams along the progress of the design. This enabled not only capturing the different affordances and impedances that emerged within different design phases, but also discovering new interaction and design thinking patterns across these phases that were not originally anticipated.

The research focused on examining two main patterns of communication and argumentation: within the architectural firm, and between the firm and other participating disciplines and consultants. The former pattern of communication involved studying design thinking and discussion sessions within the architectural firm, segments of work sessions, informal conversations, and internal meetings. The latter pattern of communication involved observing project-specific design meetings that occurred between different teams occasionally in the architectural firm, in addition to general meetings and discussions about tool and workflow development. In both patterns, interviews with key participants were conducted to inform the research.

Conducting this study required regular visits to the design teams at the architectural firm and all participating consultants. Visits to the client were not allowed, and so the discussions between the design teams and the client were communicated through the teams. To acquire the best understanding of the client’s requirements and discussions, data from all members of the architectural team, including the principal architect and project manager, as well as members from the consultants’ teams, were collected and triangulated. The duration and frequency of the visits to the participating firms relied on a number of factors including the progression of the project, the availability of team members, the frequency of design meetings and the degree of access to project data. This was determined together with each of the design teams. During these visits, collection of data for the study required a preliminary observation stage to get familiar with the practices and the nature of social interaction in each of the firms.

Most of the issues considered in the early phases of the field observation and interviewing were related to the socio-cognitive aspects of the work environment, focusing on the patterns of argumentation and negotiation of ideas. As these are very broad concepts, it was anticipated that the exact outcomes of the observation would emerge from the data and would not be pre-determined prior to the study. In all data collection procedures, the observation involved two main lines of focus in parallel to address the research questions and goals: (1) patterns of argumentation and negotiation of ideas, and (2) BIM model data exchange patterns. All data in this study was collected and maintained in accordance with the Institute Review Board (IRB) Human Subjects requirement. The identity of all the participants was held in confidence by the researcher, and all participants were assigned aliases in this research and any resulting publications. The following sections describe in more detail the data collection procedures in the study.

3.2.1 Field Observation

Before the commencement of the study, I had a meeting with (B1), BIM manager, and (P3), one of the principal architects in the architectural firm, in order to introduce the goals of the research and to identify a potential BIM project in the firm. Timeframe, duration of project, approval of participation were all taken into consideration in this meeting. Upon identifying a project, all participants, including the consultants, were provided with a brief introduction to the research study and consent forms for their approval of participation.

This was followed by informal conversations with key participants for the first month in order to get familiar with their backgrounds, experience, interests, level of engagement in the project, and level of familiarity with the tools they use in their practices. After establishing rapport, I started scheduling open interviews with some of the participants and started attending internal meetings within the architectural team during the programming phase and before schematic design to get to know the preliminary concept of the building. I also had access to some sketches and preliminary drawings. This was the same for in house and external consultants, where the first kick-off engineering meeting was shortly scheduled for the project, and informal conversations and scheduling of interviews took place for the consultants.

Moving through the progress of the project, constant field notes and memos were taken from observations in the workplace. Visits were not firmly on a regular basis, but were more dependent on the participants' schedule and the progress of the project. They took the form of "observation windows" for approximately an hour or two hours after or before scheduled interviews and group meetings, rather than fixed intervals of field observation. The purpose of these observation windows was to examine the social interactions between participants in the context of the project, follow the progress of the project, and look at the different artifacts, sketches and drawings sitting on the participants' workbenches or pin-ups on the wall. The goal of these notes was to document those informal patterns of communication and track design progress by means of personal communication of ideas and positions in each firm in order to understand the individual and collective positions and arguments of each of the participants.

Regarding data exchange patterns, I also documented model data exchange among all participating AEC disciplines. This was done by gaining access to the architectural firm's project server which was managed by (A1). All building models and other auxiliary files from all participants were uploaded regularly on a weekly basis on the server. Accessing this data allowed for recording the history of model data exchange, and identifying the main types of information that was communicated between different participants along the process. It was also important for the purpose of continuous comparison with additional non-digital material such as hand drawn sketches and other images and line drawings. The premise was that the triangulation of this data with the descriptive and narrative information from informal conversation and other sources would provide a better understanding of BIM and data exchange capabilities and what they offer versus what the teams require during the ongoing thinking process.

3.2.2 Interviewing

This form of data collection involved conducting open ended and semi-structured interviews with key participants in the design process, including members of the architectural project team, other external or in-house consultants, and any key participant whose role emerged as significant according to the data. In contrast to structured interviewing where questions are prepared in advance and oriented in path to focus on specific points of interest, open ended interviewing is characterized by non-intrusive and undirected questions where the interviewee is left to lead the line of thought. Most of the interviews were open ended. Semi-structured interviews were conducted towards the end of the study with the purpose of following up and getting more feedback on specific points of interest that emerged throughout the observation.

Interviews were scheduled based on a number of factors, including time frame and availability of participants, and often depending on specific events taking place such as a new participant or consultant joining the project, follow up after a project meeting, or a significant phase of the project being submitted to the client or consultants through the server or hard copy drawings. The goal of the interviews was, besides getting to know the background and experience of the participants, to observe and record their individual positions, needs, motivations, arguments and assumptions about their own work, in addition to tracking those positions along the process.

The content of these interviews was not pre-determined, but was developed and elaborated along the observation process. They dealt primarily with detailed specifics of the project and the participant's interaction with different tools, applications and other involved members. The content of the interviews was continuously informed by the field observation and its ongoing analysis. It also built up on emerging data from other interviews and relevant sources of data. The duration for most of the interviews was between 35 and 100 minutes, with an average of approximately 45 minutes. All interviews were audio recorded. They were also video recorded if the discussion involved follow up questions over sketches, models, documents or other artifacts that required visually recognizing the discussed information. The total number of conducted interviews was 42 interviews; all of which were transcribed, and 25 of which were fully coded and analyzed. Figure 3.2 shows a sample of a transcript carried out at the architectural firm with the (A1). An extract from an interview transcript is also shown in table C.1 in APPENDIX C: Sample Transcripts.

Most interviews took place within the firms, in or around the work space. In some instances, interviews were held in meeting rooms for privacy purposes and to avoid distraction, especially if the topic of concern involved other team members, as with (A3) and (A4) and most of the external consultants. In these interviews, the setting would typically include hard copy drawings or sketches for discussion. In other instances, interviews were held in front of the pin-ups on the wall or over hard copy drawings on the team workbench in the corridor, as was the case with (A1) and (A4). In some other instances, interviews and informal conversations would take place in the workspace, where more detailed information was needed using the computer screen or some documents on the participant's desk, as with (C1), (L2), (A1), and (A4). This was all based on the preference of the participants.

Protocol Title	An ethnographic study of interdisciplinary collaboration in BIM-enabled architectural practice (Main 03/23/09v1)
Document Code	I1-A1-02102010
Type of document	Transcript - Individual interview
Site	Architectural Firm
Subject	A1 (Project Architect)
Project	SG Building
Method of recording	Audio taping
Date Recorded	02/10/2010
Duration	55 minutes

	A1	Yeah…umm…and you can get really caught up in putting windows in and everything in Revit and SketchUp and things of that sort but it takes so much time to get the window you want and that's the trouble with this…you have to go through and do all this modeling just to get a certain size window that you want…whereas…and you're not even sure if you want that window because you're in schematic design…so it's much easier just to hand draw it…do studies…put it on drafting board with a parallel bar and draw it like that and start looking at how things fit together…how things mass out…and materials and things of that sort. Now I will take a basic Revit model which is a basic block or something which is 3 storeys high maybe and put a sloped roof on it to get an idea of what the overall massing will be…and then start to…then put a grid on the face of it and print that out and use that as my basis for sketching over…because that then gives me some parameters where I don't have to go and set up a 2 point perspective from scratch…I already have it in there but it gives me the basis to start looking at…
	I	But in the drawings…in the hand sketch…you put some information there. Would you feed that back eventually in the model somehow afterwards?
	A1	Yeah I think…we start drawing sketches and then you start looking at it in masses and stuff because you spend a lot of time just drawing in 2D or stuff…and it really helps to get it into 3D to see how it looks…you get ideas…and you know…it's kind of collaboration between the two…you draft…you go into Revit and you model something…you go back to sketch over it…you print it out and sketch over it…you go back and you try something new and you print it out and sketch over it…so…but at least we're to that point where we kind of have a general idea of the shape of the building…how it all falls together by the end of the week could be a whole different story but…you know…the general orientation and kind of where the entrances will be and how the circulation around the building and through the building will be…kind of some general public areas…so we're getting those pieces put together but as for final design that's a couple of months off…I think somewhere in April…that's when we're supposed to have a schematic design package which will be…once we get an idea of what we want schematic design package is just elevations, usually all the floor plans, sections, a site plan and perhaps a perspective or two, maybe a rendering…umm…that's where Revit comes along pretty handy…and put that stuff out really quick…
	I	Extract it out of…?
	A1	Yeah…Revit is really…really really good for getting stuff like that done…and that's where you spend a lot of time in the beginning of the project trying to get all those details worked out

Figure 3.2. Sample interview transcript with project architect (A1)

In some occasional instances, the interview took place outside the firm. This was also based on the preference and comfort level of the participants, where some such as (A4) preferred to sit in an informal setting to express her point of view without being pressured by the physical setting and context of the project. To allow for this level of comfort, these types of interviews were not audio recorded and took rather the form of an informal conversation with some brief notes taken.

In some other instances, participants provided a "guided tour" of the firm, like (S2) for the structural firm, (V1) for the A/V firm, and (E1) for the sustainability group floor in the architectural firm. This was something between an interview and a field observation. It was useful in visualizing the full capacity and potentials of the firm, understanding the working force capacity, the number of team members, and the different interactions between participants. It was also helpful in getting introduced to potential candidates for interviewing and discussion upon identifying their specific roles and tasks early on in the project. These tours also helped in understanding physical space configuration and relations. For example, seeing the auditorium simulation space in the A/V firm added a lot to the understanding of the practices of the firm and the underlying methods of calculation used by the A/V engineers.

3.2.3 Meeting Sessions

Attending design thinking sessions and project meetings depended primarily on the schedule of the project and the frequency of meetings. These sessions were video recorded to capture the ongoing interactions between participants. The duration for most of the meetings was between 45 and 200 minutes, with an average of approximately 100 minutes. The total number of recorded meetings was 11 group meetings. Selected segments of each of the meetings were fully transcribed and analyzed based on their relevance to the context of study.

The study focused on observing the following types of meeting sessions: (1) meetings in the architectural firm that involved representatives from all AEC design teams, (2) internal meetings within the architectural team, (3) meetings between the architectural team and one of the AEC consultant teams, and (4) meetings between multiple architectural teams in the firm and BIM managers. In type (1), observing a meeting with all AEC design teams represented allowed for capturing the positions of each of the representatives towards specific design issues and identifying possible conflicts. The occasional sharing the building model data in these meetings allowed for observing the discussions and argumentation patterns over the exchanged information. Type (2) allowed for a close observation of the individual positions and issues within the architectural team and the ongoing argumentation among the team members along the course of the project. It also helped identify the intradisciplinary dynamics of the team upon receiving a building model from another consultant.

For example, if an MEP model was uploaded to the server, the project manager (A2) would discuss the implications of the modifications introduced by the MEP team with the project architect (A1). (A2) would then assign roles to the (A1), (A3) and (A4) and inform (E1) and the sustainability group members of the required project goals and the other client constraints in order to respond to the MEP changes, or request a meeting with (S1) and the structural engineering team to provide input on these changes.

Other scenarios then would come into play. (A1) for example might have a specific position on how the team should respond to the MEP changes based on the available resources or BIM tool constraints. Other team members might also negotiate with (A1) and come together to reconcile, leading to a proposal that expresses their collective position in the subsequent model update. The observation focused on this kind of negotiation and argumentation process which was rich with information about how teams build up their arguments in response to different implications.

Type (3) involved discussions between the architectural team and another in-house consultant such as the estimator or external consultant such as the structural engineering team. Observing these meetings allowed for a detailed exploration of interdisciplinary architect-to-consultant negotiations and possible conflicting arguments while addressing specific design problems. Type (4) meetings were targeted to discussions about BIM-specific issues, such as dealing with the complexity of BIM tools or discussing data exchange issues with other team participants within the architectural firm. These meetings involved the participation of representatives from multiple architectural project teams, the sustainability group and BIM managers (B1) and (B2). Attending some of those meetings allowed for an informed view of the group decisions made and the data exchange mechanisms that the architectural team adopted according to the vision of the BIM specialists and the concurrence of other teams in the firm.

In the process of transcribing all the data collected from interviews, meetings and field notes, aliases were assigned for all participating firms and individuals. Audio and video recorded conversations were kept secure to protect the confidentiality of all participants. All the interviews and meeting sessions were transcribed solely by the author. All the interviews, field notes and meeting sessions were archived in a database for handy retrieval and access, and for the purpose of the coding and analysis phase of the study. This was done using the MAXQDA (2010) software.

In terms of conventions, the following convention was used for transcribed interviews: ("I" for interview – serial number of interview for the specific interviewee – interviewee alias – date (month/day/year). For example I2-E1-07142010 is the second interview for participant E1 conducted on July 14, 2010. The same goes for meeting sessions and field notes, but without an alias (e.g. N9-05242010, and M2-03162010). Other conventions include marks that are shown in the interview or meeting text in the following chapters. Breaks or shifts in direction of speech are indicated by a dash (–). Compression of text is indicated by continuous dots (…).

3.3 Coding and Analysis

This research adopted grounded theory coding as a basis for analytic induction. In contrast to theory derived by means of grand theory deduction, grounded theory coding and analysis relies on identifying emergent phenomena from the observed data and respondents through a series of steps that would 'guarantee a good theory as the outcome' (Glaser and Strauss, 1967; Strauss and Corbin, 1998). The basic idea in these steps involves the continuous examination, comparison and reading of multiple sources of data such as field notes, interviews and memos. This is followed by discovering sets of concepts, categories of phenomena, and properties that emerge from these sources of data and the different interrelationships that exist between them. According to grounded theory coding, the analysis and coding process usually occurs in parallel to the data collection process. Data examination and coding is done for every note and interview transcript promptly and built upon to use the data in subsequent interviews. Data analysis becomes useless and inaccurate if not performed in this fashion, as the process of identifying categories of phenomena from the data is an ongoing one that cannot be done merely at the end of the data collection phase.

In the process of developing codes and eventually categories of emergent phenomena, three main approaches were performed simultaneously: 1) sampling across interview and meeting texts to identify personas based on initial salient features relevant to the main research inquiry, 2) focusing on each of the personas in the text in terms of identifying their background, motivations, needs and goals, and tracking their experience and feedback along the progression of the project, and 3) identifying patterns of interaction based on classes of events that take place between different participants, both within teams and across teams. Below I describe some of the methods used to code and analyze the data; open coding, axial coding and selective coding, in addition to an overview of the codes and super ordinate categories identified in the study.

3.3.1 Open Coding

The objective in this kind of coding was to identify emergent categories of phenomena taking place in the studied firms and assign meaning to them. The identified categories would then be decomposed into a set of dimensions. Strauss and Corbin (1998) suggest that these categories exist along a certain continuum, and that the dimensionalization process involves describing the locations and degrees to which the categories fall on that continuum. This would enable identifying further subcategories and their corresponding properties. Open coding requires the comparison of the data, where concepts are formed directly from the notes and observations. Every piece of data contains information that should be categorized and processed to some extent.

In this study, transcripts of selected interviews, meetings and field notes were fully and progressively analyzed, and an initial description and naming of preliminary codes was generated for most passages of the text. This was done in accordance with the open coding phase of grounded theory, where the goal was to describe the collected data in terms of its conceptual dimensions. Initial codes were developed to organize these descriptions, and these codes were discussed with an inter-rater reliability group, composed of three researchers, to achieve a level of concurrence. This process of "opening up the text" by labeling what is seen as potential phenomena was an ongoing process, in parallel to interviewing and observation, to build on continuous emerging data. Many preliminary codes were created in this stage (figure 3.3).

Rather than reducing these numerous codes to a reasonable number of coding categories, the goal was to formulate accurate and reasonable descriptions of these initial codes and understand what they mean not only within the specific text but also within the larger context of the data related to the personas and the different interactions in the firm. These descriptions were developed through multiple iterations based on their potential importance and relevance to the basic research inquiry, comparisons and alternative interpretations of the text, and verification and concurrence with the inter-rater reliability group. In this phase, numerous codes emerged but were too broad and open ended at this point, and required further refinement into categories that were not just concise but also meaningful to the basic inquiry.

	A1	It's kind of a…it's kind of a live type of collaboration ["**live/real-time collaboration**"] where they build their model and we build ours and we start to see things that don't work and things that do work ["**examining shared models**"]…you know they don't go in and put all the miscellaneous steel in there but they will put the major steel beams and steel framing and columns in there…they will be in our model showing up ["**shared building elements**"]…but if they decide to move something…you know…as it gets later in the game you…there has to be a collaboration there because it will show up in our ["**model complexity in detailed design**"]…if we're doing a detail and we're using their column in our detail and drawing how the brick goes around their steel column and their steel column moves then we go and print the drawings and their steel column isn't there anymore…so things of that sort could actually affect ["**ramifications of 3D model editing**"]…because back when you had CAD you just drew a symbol for a steel column and that was that…you don't worry about moving ["**simplicity of representations in CAD**" vs. "**complexity of BIM 3D models**"] but now you have to…you know…check everything because things will move ["**extensive conflict checking**"] and…I've come across that a lot ["**frequent conflict checking**"]…beams go up and down three inches and now your drawing doesn't look the same ["**requiring extreme accuracy**"]…so…and that can happen the day of printing…so it's just one of those things

Figure 3.3. Sample of the labeling of potential phenomena in the open coding stage ("*opening up*" of text)

Figure 3.4 shows some preliminary conceptual categories and super ordinate categories established in the open coding stage.

SUPERORDINATE CATEGORIES	CATEGORIES	SUPERORDINATE CATEGORIES	CATEGORIES
Exchange of data	Limitations of modeling-analysis exchange Smooth data flow Partial use of model data Correctness of model data Level of confidence with data exchange Shared repository of building data	Tool affordances	Conflict detection and resolution Parametric flexibility Collaboration support Uses of model
Representing information	Auxiliary data representations Representation of information Early data input	Work mechanisms	Work distribution Phasing of tasks Task accomplishment
Communication	Communication patterns Interpreting client requirements Ambiguity in requirements Primary communication person Conflicting intents Previous collaboration Decision making authority Level of collaboration	Individual perspective	Analyst viewpoint Personal preference of tools Expertise New experiences Modeling vs. analysis interfaces
Tool constraints	Resistance to BIM Limitations of modeling tool for design Complexity of interface Computational limitations of analysis tool Learning curve Model ownership Tool adaptability to mode of work	Shared perspective	Meeting target values Shared position Concurrence among teams Design constraints Matching positions and goals

Figure 3.4. Preliminary categories in the open coding stage

3.3.2 Axial Coding

The goal in the axial coding phase of the analysis was the continuous refinement and verification of categories and establishing connections between them. This usually takes place once a saturation point is achieved, where the same categories and themes keep emerging with no new divisions or interpretations. In this phase, links are usually discovered and explained between dominate themes in a way similar to concept mapping. This ongoing search for links and relationships required a process of revisiting and examining for not just the results of the open coding phase, but also all the raw data and observations prior to open coding. The process of discovering links and relationships between the basic identified categories usually takes some concepts into consideration, such as causal conditions, phenomena, context, intervening conditions, action and interactional strategies, and consequences (Strauss & Corbin, 1998). Causal conditions refer to instances of acts that materialize a certain phenomenon. The property that each instance within a specific phenomenon holds is defined as its context. Intervening conditions describe those circumstances that affect the outcome and progression of the studied phenomena through a process of action and interactional strategies. In all of these phases, the effects and responses to the phenomena are known as consequences.

Further distinction and development was carried out for the codes in this phase. Revisions, eliminations and additions of codes were done continually along the process. A lot of refinement was done to arrive at clear distinctions of the code descriptions, mainly focusing on similarities and overlaps. The more multiple instances were recorded in this phase for the codes, the more it was ensuring that they would be taken to a further level of analysis and evaluation. This was all done along with the data collection and field observation, and what resulted from the new reading of text and revisits accordingly. The inter-rater reliability group played an important role in verifying the fit and relevance of the refined codes and description to the research inquiry.

Codes were grouped under categories that appeared to achieve best fit and portray as much as possible a main theme that unifies these codes. For example, codes such as data transfer limitations, partial use of model data, mapping between tools and conditions, unused data, smooth data flow, shared repository of building data, understanding concepts of other disciplines, frequency of model data exchange, unnecessary data transfer were initially placed under the preliminary super ordinate category *Exchange of Data*. These still seemed too broad and needed further revision.

After multiple iterations of refinement, addition and elimination, and upon verification by the reliability group, the initial super ordinate category *Exchange of Data* and some of the subcategories within it were seen as part of a larger context which involved interactions within and across teams. Other subcategories were seen as belonging to other contexts. For example, codes that involved the nature of interaction among teams and participants were included under the super ordinate category *Interaction across Teams* such as understanding needs of other disciplinary participants, and patterns of exchanging information. Others that involved interoperability problems such as discrepancies in conventions and parameters, interface and data transfer limitations, incomplete information from the tool, and incorrect information from the tool were included under the category *Incompatibility among Tools*. Others that involved advantages of BIM tools such as shared repository of information, and efficiency and accuracy were included under the categories *Affordances with respect to Collaboration* and *Affordances with respect to the Tool* respectively.

3.3.3 Selective Coding

Selective coding provides central themes to be examined as the focus of inquiry and identifies those that are incomplete but deserve further attention in future research. In-depth analysis is usually conducted for those selected themes to validate the previously defined links and relationships in axial coding, and create a more solid description of the context of inquiry. Both data collection and coding end in this phase, where the same types of data and themes emerge without further insight. Further revision and grouping of codes under super ordinate categories was done in order to arrive at overarching themes related to the research inquiry. Continuous analysis was conducted for the final categories to check for overlooked meanings or false interpretation and examine possible fit with the established categories. This was done continually until there were no more possible reductions or further emerging themes. Figure 3.5 is a screenshot from the MAXQDA (2010) software showing the final conceptual categories at the end of the selective coding process. The top left portion of the screen contains the archived documents (notes, interview and meeting transcripts). The bottom left portion shows the codes and super ordinate categories. The right portion of the screen shows one of the open documents.

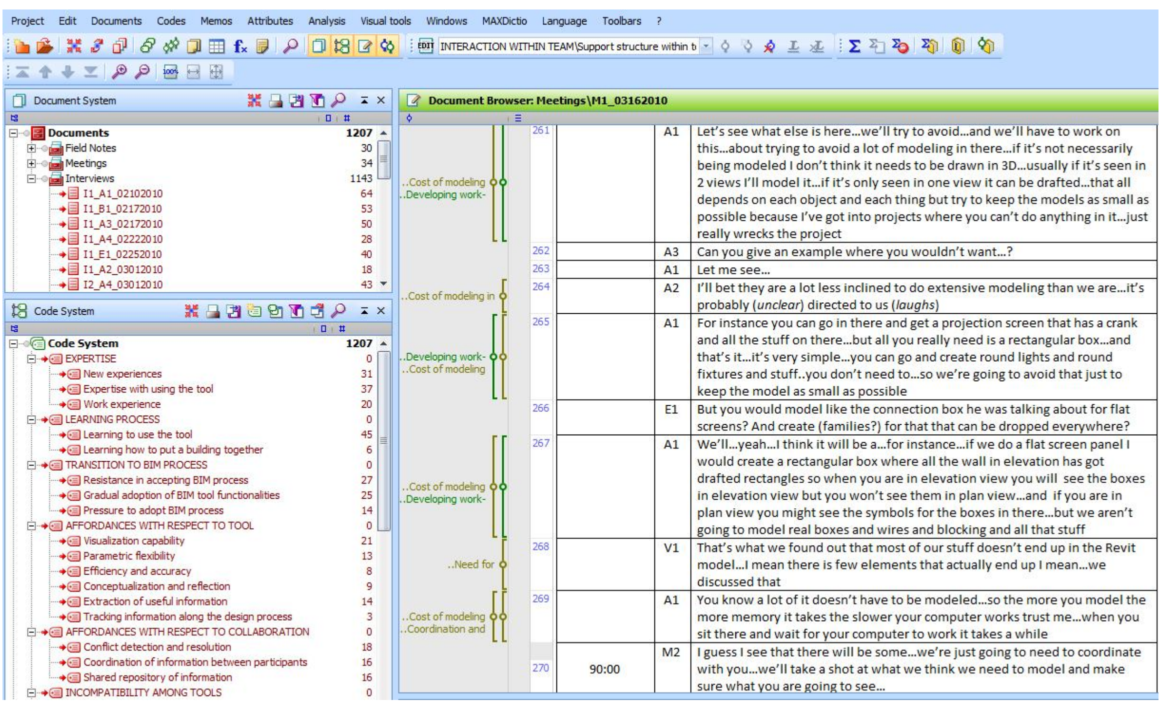

Figure 3.5. A screenshot of the MAXQDA (2010) qualitative analysis software showing the main emergent conceptual categories by the end of the selective coding process

Although this method of coding and analysis builds on concepts and constructs of grounded theory, the goal and outcome of the research is not establishing a theory per se, but rather providing a robust “thick description” (Geertz, 1973). This description involved the main emerging categories and themes, and their corresponding properties and dimensions. As a clear view of links and relationships was established between the predominate themes, both a narrative and graphic representation of the themes was constructed along the study, describing the experience and goals of the personas and the nature of interaction between them. This was supplemented by examples of text passages from the different categories. The main categories, descriptions and examples were presented to the participants for feedback and discussion.

3.3.4 Codes and Categories

Higher level codes, or super ordinate categories, emerged through the use of the approaches mentioned at the beginning of section 3.3, especially the second and third approaches. The super ordinate categories that emerged were as follows (APPENDIX A: Coding Guide provides detailed definitions and examples for each of the codes):

1) *Expertise*, which included subcategories of new experiences, expertise with using the tool, and work experience;
2) *Learning Process*, which included subcategories of learning to use the tool, and learning how to put a building together;
3) *Transition to BIM Process*, which included subcategories of resistance in accepting BIM process, gradual adoption of BIM tool functionalities, and pressure to adopt BIM process;
4) *Affordances with respect to Tool*, which included subcategories of visualization capability, parametric flexibility, efficiency and accuracy, conceptualization and reflection, extraction of useful information, and tracking information along the design process;

5) *Affordances with respect to Collaboration*, which included subcategories of conflict detection and resolution, coordination of information between participants, and shared repository of information;
6) *Incompatibility among Tools*, which included subcategories of incomplete information from the tool, incorrect information from the tool, discrepancies in conventions and parameters, and interface and data transfer problems;
7) *Cost of Tool for Participants*, which included subcategories of cognitive overload, design conceptualization problems, ease of use, need for interaction with participants within team, and need for representations external to the tool;
8) *Cost of Tool for Teams*, which included subcategories of: rigidity versus flexibility, cost of modeling in 3D, coordination and management overload, and need for interaction across teams;
9) *Disciplinary Positions and Preferences*, which included subcategories of relevant versus irrelevant information, perception of BIM representations, personal preference of tools, level of confidence with the tool, human judgment, desired functionalities, and information needs;
10) *Interaction within Team*, which included subcategories of conflicting positions within team, team reconciliation and negotiation, pressure within team, status and comfort level within team, assignment of roles and tasks, support structure within team, insufficient BIM data input, team knowledge history, and disconnect among participants;
11) *Interaction across Teams*, which included subcategories of conflicting positions across teams, reconciliation and negotiation across teams, concurrence among participants, scope of involvement, understanding needs of other disciplinary participants, participant status, developing workarounds in tool, and patterns of exchanging information; and

12) *In Principle versus In Practice*, which included subcategories of: expectations of BIM, workflow efficiency, and phase of engagement in the process.

Most of the categories appeared to emerge from and align with the initial goals of understanding how design intent is communicated among interdisciplinary design teams. In terms of collaboration and interaction among participants, some categories were not anticipated, especially those that involved individual positions or intradisciplinary interactions, such as *Disciplinary Positions and Preferences* and *Interaction within Team*. In terms of BIM tool capabilities, the *Transition to BIM Process* and *In Principle versus In Practice* categories and the range of codes within them were also unanticipated.

Determining the salience of the codes and super ordinate categories did not necessarily or solely depend on the number of instances of occurrence in the text. Many codes recorded very few instances of occurrence throughout the transcripts, such as the need for interaction with participants, but were seen as very relevant to the research inquiry. Others, such as the cost of modeling in 3D, recorded much more instances and were seen as equally salient. Determining that a code or high level category was salient however relied on a combination of its relevance to the basic research inquiry, number of instances of occurrence, and the diversity within each code.

3.4 Verification

The research implemented a number of approaches for obtaining higher levels of reliability concerning the proposed description, the established categories of phenomena, and the generalization of results to other contexts. A number of ways are typically used to evaluate the reliability of the research (Krueger, 1994). These include inter-rater reliability, triangulation, and transferability. These are briefly described below.

3.4.1 Inter-rater Reliability

Inter-rater reliability is a process where concurrence is established among more than one coder in trying to find rigor concerning the methods used to code and interpret results. The goal of this process is to identify the degree of similarity in judgments between independent reviewers with a considerable agreement between them which indicates high inter-rater reliability (Touliatos and Compton, 1988). This should generally be within a 75-80% range of considerable agreement.

The reviewers in this study were three graduate students in the fields of software engineering, public policy and architecture. They were all familiar with qualitative analysis methodology, ethnography, and grounded theory coding, as they were mostly using them in their own fields of research. The inter-rater reliability process worked as follows. First the reviewers were introduced to the research problem, questions and goals over several meeting sessions. In the open coding phase and after establishing some preliminary labeling, there were several informal discussions with the group about the preliminary codes. The discussion involved the different interpretations of the reviewers of the established labeling. There were often some rather heated arguments among the group concerning alternative interpretations and reading of the text, especially with different disciplinary backgrounds involved. Codes were then accordingly eliminated, retained or added based on the feedback of the group.

In subsequent phases of analysis, a formal document was provided to the reviewers to assist in the verification process (APPENDIX B: Instructions to Reviewers). The contents of the document were as follows. The research questions were listed to give the reviewers an idea of how the selected codes attempted to address those questions. A list of all to-date codes was provided, including all codes, their instances of occurrence, and their higher level categories. In order to give the reviewer more insight into the meaning and context of use of the codes, a brief guide of all codes was provided containing a short explanation of what each code represented in addition to an example extracted from multiple transcripts. A sample transcript of an interview with one of the subjects was also provided. The reviewers were asked to read the sample transcript carefully and use the provided codes in the guide and any other additional codes that they saw as appropriate. They were asked to highlight phrases or paragraphs and either use one of the codes or introduce a new one. Meetings were then held with the reviewers to discuss and validate the coding scheme according to their interpretation. The MAXQDA (2010) software was used as a shared platform for the discussion, where the reviewers' coding was embedded together with the author's original coding scheme.

A continuous process of negotiation and discussion with the reviewers then followed, over multiple sessions, in parallel to the analysis and coding process. The final phase of discussion involved not just revising sample transcripts but going through the coding guide line by line and code by code to verify best fit and naming of the codes and higher level categories. This was helpful in expanding the scope across all coded transcripts, as the reviewed examples and definitions enabled a wider range of discussion around the used codes and higher level categories. Once a considerable level of concurrence was achieved concerning the established categories, they were adopted for the rest of the analysis and description process.

Feedback from the reviewers involved a number of issues at different degrees of detail, including: 1) renaming or rephrasing codes to match their definitions or intent (e.g. *visualization* to *visualization capability*, or *frequency of exchanging information* to *patterns of exchanging information*; 2) restructuring some categories by moving codes from one category to another to achieve best fit; 3) fine tuning the definitions of some codes to understand if they were too broad and required splitting into multiple codes, or if there were overlaps with other codes that would require merging; 4) defining the scope of some codes (e.g. does *conflicting positions* involve positions about the design process or the use of the BIM tool, does it involve positions across teams or within the team?); 5) suggestions of overarching themes in the description; and 6) clarifying the implications and dimensions of some of the codes within a category (e.g. in the category *Interaction Across Teams*, the social component of *participant status* and the cognitive component of *understanding needs of other disciplinary participants* make up a socio-cognitive account that contributes to *developing workarounds in tool*).

3.4.2 Triangulation

During the analysis and coding process, a process of triangulation usually takes place, aiming at increasing the validity of the proposed description (Sevigny, 1978). This process incorporates different viewpoints and methods, and other sources such as data from the project building models, sketches and drawings, informal conversation, field notes, personal experience-based interpretation and others. This sociological process of combining multiple stances helps view the situation from a variety of perspectives. Using these and other triangulated techniques was helpful for cross-checking, and searching for more varying perspectives on complex issues and events (Wolcott, 1988). This process was conducted early on during the analysis and was revisited at several intervals, especially at the end of the coding process after much more insight was provided from the completed data. There was constant comparison between the field observations and the interpretations emerging from the interviews and meeting sessions. This led to further refinement of the codes and categories resulting from the coding and analysis process. Triangulation using data from the project BIM representations, freehand sketches, spreadsheets, and other project documents was very significant in the verification process. Interview samples, field observations, and the resulting emergent codes from the analysis process were all continuously tested against these representations for their applicability and conceptual fit. Model updates through the project server were the basic source of data used for this verification process. The archival of all the files on the server was necessary for doing the conceptual fit comparisons.

3.4.3 Transferability

The main focus after the inter-rater reliability and triangulation processes was how to address the relationship between the description and findings in the specific context of observation and their applicability to other contexts, or what is known as transferability (Lincoln and Guba, 1985). Transferability describes the degree to which results from any qualitative research can be generalized or transferred to other settings or contexts. Transferability was proposed by Lincoln and Guba (1985) as the qualitative counterpart of external validity in quantitatively oriented criteria. The primary concern is therefore not to generalize from the analysis or description of the observed firms, but rather to describe the properties and dimensions of the emergent categories of phenomena related to design intent communication in BIM. The goal becomes to discuss which of these properties and dimensions are transferable to other contexts. This is further elaborated by thoroughly describing the research context and laying out the assumptions that were central to the research in each case. This provides the basis for future comparisons to any other BIM-enabled practice context, where researchers who would like to transfer the results to a different setting will not just generalize from this case but will be consciously aware and responsible for the sensitivity of that transfer (figure 3.6).

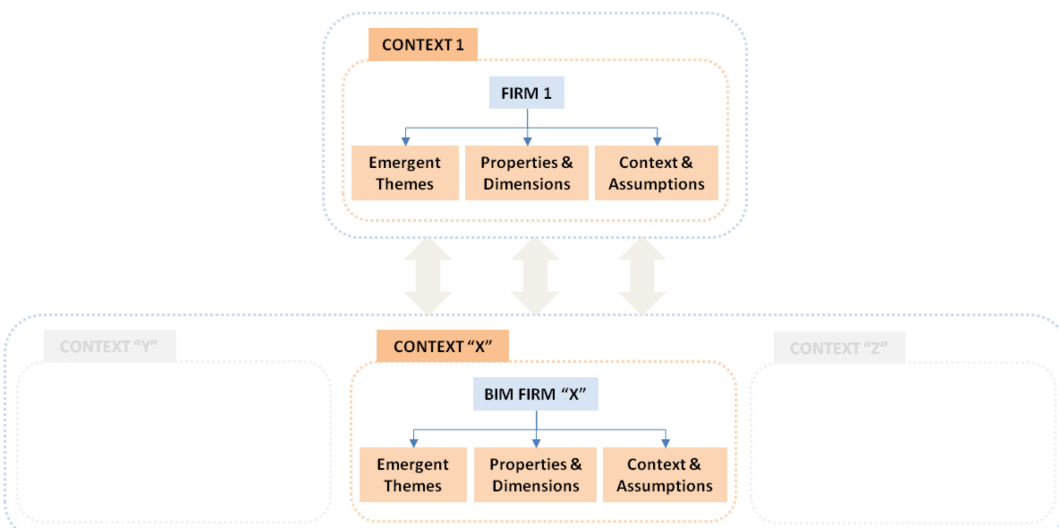

Figure 3.6. Transferability of specific context of observation to other contexts

Based on the transferability process, the research aims to identify in detail the main characteristics of the observed context in relation to the larger set of cases of AEC design teams in BIM-enabled practice. The main focus will be on the relationship between the results of the research and that larger set in terms of basic similarities or outlier features. Identifying this set of cases will be done through analyzing generic business models of BIM practices offered by software vendors, construction companies or firms, as discussed in precedent case studies or annual survey reports. This will determine where the observed context in this research lies along the spectrum of cases in the AEC industry. This will be discussed in more detail in Chapter 7.

3.5 Additional Methods of Analysis: Personas

3.5.1 What are Personas?

The concept of personas was introduced and popularized by Cooper (1999) in the field of product design, and later adopted in human-computer interaction (HCI) and related fields, such as information science, technical communication, graphical and interactive design, industrial engineering, applied and workplace anthropology, and cognitive, applied, or industrial/organizational psychology. In contrast to the notion of *typical users* of a certain product, personas depict fictitious, memorable, specific, and concrete representations of target users that remain conspicuous in the minds of those who design and build products (Pruitt and Adlin, 2006). By placing an engaging and actionable image on the user, personas remain live in the minds of developers.

Historically, the notion of personas materialized after several precedents of user representations in marketing and branding. One of these early user representations is Moore's (1991) "target customer characterizations" which provides an understanding of individual customers in work environment contexts by portraying images of customers rather than market segments. These images contain characterizations such as personal profiles, job descriptions, technical resources, individual problems and "day in the life" contexts. Upshaw's (1995) "customer indivisualization" provides a similar but a tighter and more detailed description, where descriptive profiles and indivisualized profiles underscore personal viewpoints and purchasing decisions of customers instead of viewing them as being part of a mass population or market segment. Hackos and Redish's (1998) "user profiles" represent further more accurate descriptions of users, including unique types or classes of users. Carroll's (1995) "scenarios" extend the point of focus to include not only users but also other dynamics such as systems and context, and networks of actions and reactions, implying that users or actors are just one of the components of the system. Other representations such as Constantine and Lockwood's (2001) "user roles" and Mikkelson and Lee's (2000) user archetypes highlight specific user characteristics such as interests, needs, concerns, responsibilities, goals, technical skills, activities, behaviors, expectations, in addition to the larger context of the user's role, the objectives of supporting that role, and the market size of that type of user.

Cooper's (1999) "personas" depict hypothetical archetypes of actual users, where imaginary people are created to represent target users, but are only truly representative of actual users upon the use of the designed product. Cooper's approach to personas – a goal-directed design approach – involves understanding distinct user goals, behaviors, tasks, and simple demographic information, and designing towards their central motivations and needs to achieve sustainable solutions. In this approach, the degree of specificity and detail of persona description give the personas their value. Cooper argues that design; product design solutions in this case, can be profoundly informed with goals being at the cornerstone of this approach.

3.5.2 Why use Personas?

Questioning the use of personas is typical; why not rely on conventional user representations and market segments? The answer lies partially in Cooper's (1999) statement: "*To create a product that must satisfy a broad audience of users…you will have far greater success by designing for one single person*". By focusing on a smaller group of specific users, it becomes easier to design for the larger population. The premise is that a self-centered approach that is based on needs of participants is more efficient and promising than the typical user-centered approach that denotes the abstract user.

The term "user", according to McGovern (2002), is "*a catchall and a mean-nothing word that is more technology centric than people centric*". Without enough information about the user, it is hard to assert that any given product is being designed or built *for* that user, who is or is not the target user, which users are satisfied and which are not, or where points of conflict exist among different groups of users. These issues are significant when the tool, process or product in question involves interdisciplinary collaboration between multiple teams and participants, each encompassing their own – possibly conflicting – motivations, goals and viewpoints.

To acquire information about users, it is important to understand that they are "real people" with needs, preferences and desires, and that studying those characteristics is more complex than identifying "user requirements" as in specification documents. Users are fairly complicated and vary in their individual goals and perspectives. To anticipate their recognition of a specific tool, process or interface, it is necessary to identify their background, age, work experience, computer literacy, educational level, and other types of personal information (Nielsen, 1993). By exposing such detailed, specific and meaningful information, personas acquire some level of credibility that most user representations may not have. This credibility is augmented when the different assumptions about users are made explicit, and when information about users is materialized and *humanized*, thus providing a concrete and well established alternative to the abstract user. It is through this constraining and tightly defined representation that multiple opportunities and possibilities of designing the product can be explored.

3.5.3 Why Personas and not "Nebulous Users" in AEC?

As mentioned in section 3.5.1, the implementation of personas has emerged out of the field of product design and is being adopted in other related disciplines. The question is: why employ personas in the AEC domain; why not rely on the *nebulous user* to develop software tools that support information exchange mechanisms as well as practices such as sustainability analysis and constructability review?

To answer this question, it is important to realize that AEC projects are complex projects that have a number of unique characteristics. First, multiple participants and stakeholders are involved in AEC projects. Each disciplinary participant demands some type of information throughout the process, and therefore the overall pattern of communication requires the continuous exchange and update of information. Second, as individual expertise and work experience play an important role in practice, these frequent updates of information often take place tacitly in the heads of the different participants (Kreiner, 1995). Third, AEC project workflows and practices are temporary and customizable in nature (Gann and Salter, 2000), vary across projects, organizations and single project lifecycles, and are sensitive to the continuous and frequent interaction between different organizations with their unique social cultures (Nardi, 1996; Taylor and Levitt, 2007). Fourth, a conflict exists between standardization efforts based on the need to integrate product and project management on the one hand, and the inclination to adjust software tools and information systems to local and organization-specific project requirements on the other.

As this research is concerned with exploring communication issues in the AEC industry, and specifically in BIM-enabled practice, it involves three main actors; researchers (the author), developers (BIM software vendors), and users (participants in AEC teams). Most efforts by researchers and developers have focused on generalized data models of information systems that do not explicitly formalize AEC project workflows and practices (Hartmann et al., 2009). In general, those who research, study and observe users are not usually the ones who actually design or implement the software products. Developers have also not demonstrated a sufficient understanding of the tacit knowledge of AEC participants to develop systems that respond to local project contexts. This resulted in a gap between the promised benefits of those systems and how practitioners use them in AEC projects (Hartmann, 2008). In addition, the intensive process of commercial software development and the lengthy update delivery cycles do not allow for an efficient and timely response to the detailed needs of users. The premise is that developers, aided by researchers, would have a better and *richer* picture of the goals, preferences and expectations of each of the participating disciplinary teams, versus what *they* think typical users like based on market segments or abstract concepts.

Conclusion

This chapter presented the methods of study for this research. Through precedent examples in the architectural profession and technology development, it highlighted the importance of qualitative research and ethnography with respect to the main research problem and goals of the study. It demonstrated how ethnography, through field observation and interviewing, was used as the main methodology to identify the types of interaction occurring in the context of BIM-enabled practice.

The chapter also introduced the unit of theoretical analysis and inquiry (the persona), as an additional method of analysis, seen through interactions with other participants and artifacts in the context of practice. It demonstrated how personas portray a richer picture of the preferences and goals of each of the AEC practitioners working in a collaborative context featuring a shared BIM model and a set of concurrent or conflicting positions. Introducing these personas in this sense aims at narrowing the gap between the promised benefits of the BIM-enabled process and what AEC practitioners actually require in terms of tools, methods and workflows in day-to-day practice, rather than relying on the “nebulous user” perspective which may not necessarily represent or satisfy *all* users.

The chapter also discussed the data collection procedures, featuring field observations, meeting sessions and open ended and semi-structured interviews, as well as the process of transcription, coding, analysis, and verification of qualitative data using grounded theory coding. The main conceptual categories identified in the study were Expertise, Learning Process, Transition to BIM Process, Affordances with Respect to Tool, Affordances with Respect to Collaboration, Incompatibility among Tools, Cost of Tool for Participants, Cost of Tool for Teams, Disciplinary Positions and Preferences, Interaction within Team, Interaction across Teams, and In Principle versus In Practice.

CHAPTER 4

INTRODUCING THE PERSONAS

This chapter introduces the main personas that were identified in the study. These personas were selected based on the most salient characteristics related to the basic inquiry of this research. The chapter discusses the significance of using personas in the context of AEC practice, and specifically in studying BIM-enabled practice. Archetypes from each participating team in the project under study are introduced, focusing on their positions, goals, preferences and expectations regarding both the discipline they represent and the representations and tools they interact with in their everyday practices.

4.1 Introduction

The dissertation attempts to expose the contexts of interaction among different disciplinary participants and teams in a two-step process. This chapter introduces the personas that portray images of AEC practitioners and their goals and needs. Chapter 5 highlights specific events that appeared as salient throughout the SG project that demonstrate the nature of interaction across teams and practitioners. The following sections introduce personas chosen in the study according to their relevance to the research inquiry. Sections 4.2 and 4.3 present personas in the architectural team, section 4.4 presents an in-house consultant in the architectural firm, while sections 4.5, 4.6, 4.7 and 4.8 present personas belonging to AEC consultants; the landscape/civil engineer, the MEP coordinator, the structural engineer, and the A/V engineer respectively.

4.2 The Expert Modeler

4.2.1 Background

One of the key participants in the architectural team was (A1), a young architect who was relatively new to the firm. He had just joined six to seven months before the start of the project. (A1) graduated in 2000 with a bachelor of arts in design and pursued a masters degree in architecture while working professionally at the same time for an architectural company and a famous A/E firm. He finished his architectural registration exams and acquired his license in 2009. (A1) was the lead project architect for the SG project. He had been involved previously in other firms in a lot of production work and in specific phases in projects, but was never dedicated to one project from beginning to end. This was his first project architect job and so it was a new experience for him. Most of the effort and load in this project was handled by (A1), in addition to coordinating and communicating with in-house and other AEC consultants. He was also in charge of modeling and sending out updates of the central BIM model to consultants. His role however was more of a production role rather than a designer.

(A1) was proficient in 3D CAD modeling tools. He used a lot of FormZ in his school years and for his thesis work. During his work as an intern, he got more familiar with other tools such as SketchUp, AutoCAD 3D and AccuRender, and got interested in understanding the three dimensional aspects of a building through the process. With the transformation to BIM tools, (A1) got to work on a lot of projects using Autodesk Revit. He was the only one using it at his previous firm, and so it was a self learning experience for him that did not involve collaboration with other architects, but he was the person that people would go to for support and to ask questions. (A1)'s confidence in using Revit and CAD modeling packages in general gave him a reliable position and status within the firm as well as the project team. AEC consultants also would go to him to ask questions if they were stuck with modeling technical issues. Although relatively new to the firm, he gained high status among other project team groups, but as an expert modeler more than a designer. (A2), the project manager, and (P1), the principal architect, were confident that (A1) would get the job done production wise, but (P1) was occasionally hesitant to rely on his design decisions.

Figure 4.1 describes the main tools and representations used by (A1) in relation to the BIM base model which is shared by all participants via the project server. (A1) relied mainly on the Autodesk Revit Architecture package, both as a conceptualization and production tool, in addition to freehand sketches which he used in the schematic design phase in conjunction with Revit.

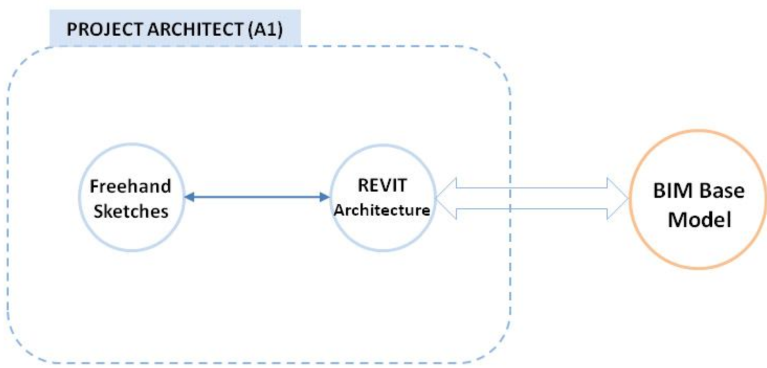

Figure 4.1. Relation between the tools and representations employed by the project architect (A1) and the BIM base model in the SG project

4.2.2 BIM as Design Thinking Tool

For (A1), who was an expert in many 3D modeling packages, Autodesk Revit became not just a production tool but also a design thinking and conceptualization tool which offered different layers of information and representation, such as space adjacency and project cost. From previous experience, he would use Revit as a tool to produce basic schematic building blocks and geometrical modules to study relations and proportions of programmatic spaces. This was a *stacking* process for (A1):

A1: *So we start seeing how things stack and work out, because you have all the parts and pieces of the building but you have to make sure that they stack, and get your 3 floors and* *then you have to start kind of working out spatial relationships with that, and getting all the building programs kind of work together.*

In this process, the horizontal and vertical arrangement of modular spaces was the main driver for composing the form and function of the building:

A1: *I've started arranging those kind of in a grid of what the structure may lay out to be, so I've got all three floors laid out in one floor and just start to align things and see square footage wise how we fit things together – you know certain spaces need to be next to other spaces – and just try to get an idea for the massing.*

(A1) found Revit to be an ideal environment to carry out this process. It allowed him to continuously organize his building blocks within the constraint of the tentative structural grid throughout the schematic phase until a satisfying solution was achieved. He saw the automatic adjustment feature of Revit as a facilitator during this process:

A1: *First of all we use a little programming portion of what we're doing - we're still doing that room by room and kind of laying out each room. Now each one of those rooms is in a group, so I copy that group - whenever I make changes to it, it will automatically change.*

With this feature and others in mind, (A1) set up the project and the associated workflows in a way that takes advantage of the functionalities of Revit – especially parametric functionalities – to the fullest and at the same time allows for efficient and flexible response to ongoing design development or to any anticipated variations. One of the issues that (A1) attended to early on in schematic design was the continuous fluctuation of the square footage of the building:

A1: *They [client] have got a certain amount of money but at the same time the construction market is so volatile that we're not sure if we can build 80000 square feet or a 100000 square feet. And essentially since they're getting this money from the state they want as much building as possible. And so we're going to try to get them as much as possible but just have to be flexible at the same time.*

(A1) tackled this issue by means of a systematic but flexible approach, where he used the modular system in the BIM model to account for anticipated additions (and possibly reductions) to the building square footage:

A1: *We're looking at kind of adding bays on to the end of the building – and we have 3 bays – like a 30 or 40 or 50 or 60 foot segment – something significant – because if you had a 10 foot bay on the end of the building that's kind of space that's not really usable for classrooms or things – so we're looking at providing the option of – if the bids come in at a certain amount we can add on 30 feet of building and just add on another bay or we can add on 40 feet – just kind of stretch the building a little bit on the end so it's relatively easy to fix.*

In doing so, (A1) worked with the modular system with an eye on both square footage and project cost to satisfy the requirements of that phase:

A1*: The old plan had a lot of extra lobby space in it so essentially we just came through here [in the floor plan] and just chopped out different parts and pieces and that affected in the spreadsheet – affected a lot of this other stuff – numbers down here – so we're actually less than what we put in here right now.*

According to (A1), this approach paid off at the end of the schematic phase because everything was set up early on, even when there was an unanticipated delay in progress and funding, and several iterations concerning the final square footage of the building:

A1*: I mean we were on hold for a month or so and then we said ok let's go ahead with schematic design so we did all this in about a week or a week and a half to get it out to them – and not a lot changed – I mean a lot changed but the first thing was in Revit so all the drawings were kind of set up.*

He also used the "design options" feature in Revit to develop different design schemes to present to the client. These schemes represent standalone alternatives for specific portions of the building:

A1*: It works well for plan layouts – if you're doing office layouts or something you can do option 1 and then you turn and then you turn it off and you have option 2 and it will pop up – kind of standalone options.*

Although (A1) was an expert modeler, he did not rely exclusively on Revit as a tool from beginning to end because he believed that *"as much as you get out of Revit it does tie you down somehow"*. He tried especially at early stages not to get into Revit as long as possible in order to get *"more stuff on paper"*. His approach was rather a back and forth process, where he would lay out basic massing and geometry in Revit and continue more detailing and material study on top through freehand sketching:

A1: *Now I will take a basic Revit model which is a basic block or something which is 3 stories high maybe and put a sloped roof on it to get an idea of what the overall massing will be and then start to put a grid on the face of it and print that out and use that as my basis for sketching over – because that then gives me some parameters where I don't have to go and set up a 2 point perspective from scratch – I already have it in there but it gives me the basis to start looking at.*

This was always the case during schematic design, where it was hard for (A1) to manage everything in Revit although he preferred to have everything embedded in the model or at least in digital format to propagate the information throughout the process. (A1) however found that he can easily get caught up in redundant or unnecessary detailing in the modeling tool, particularly in schematic design where he is not even sure whether he would use those details later on. He therefore preferred to hand draw these details and test some massing and material studies on alternatives of a base or raw model, then work in alternation between the model and the freehand sketches:

A1: *It's kind of collaboration between the two – you draft, you go into Revit and you model something, you go back to sketch over it, you print it out and sketch over it, you go back and you try something new and you print it out and sketch over it.*

4.2.3 Capturing the Essence of the Tool

(A1) had worked on several Revit jobs previously and this allowed him to grasp many of the features of the tool and orchestrate the Revit modeling aspect of the project among all AEC consultants. He was responsible for setting up sheets and preliminary modeling standards within the team, as well as managing the project web server for exchanging model data among all participants. His expertise enabled him not only to specify modeling strategies for his team and for consultants, but also to recognize which methods would be successful or not with respect to time, file size, practicality, coordination and other issues.

(A1) expressed strong conviction in the advantages of Revit in terms of coordination, efficiency, conceptualization, tracking of information and visualization. At the same time, he demonstrated a balance between understanding the functionalities of the tool and capturing the essence of the tool. This was essential for him because it gave him the sense of being in control and not being manipulated by the complexity of the tool, and so he emphasized things like being able to "*get a quick design without getting bogged down with all the Revit buttons*" and not getting "*caught up*" in how Revit forces users to work in a certain way. For example, the way (A1) used Revit in schematic design showed how he understood that the tool could force its users to model walls at a level of detail that is not quite necessary at this stage. He developed ways however to overcome that problem:

A1: *Just because you can draw a wall with gyp board and metal stud and sheathing and insulation and brick and all that it doesn't mean you have to – you can go into Revit to draw just a 12 inch wall and use that as kind of a holding place – and you can paint it so you don't have to do all the material stuff – you can just do a paint to do a schematic design.*

He realized that some architects in his team or in the firm were stuck and struggling to define that level of detail, and are frustrated with the additional setup at the front end that they had to do:

A1: *But a lot of people get caught up – everybody says there is a lot of front end work to get everything just right – well you could think of it like that but you don't have to sit there and figure out all the details – it's still like drawing with a fat marker you know in the beginning – in Revit you can do that still instead of picking out you just use the generic wall – you don't need to get into what kind of window frame is this which a lot of people do – so there are ways to do it.*

This understanding led him to think that much of the overload and excessive setup that architects in his team complained about resulted from the notion that a sophisticated tool such as Revit, while enabling the automatic extraction of details or sections from a single model, can result in a lot of unnecessary information. This introduces an additional burden in terms of coordination and management, and is not necessarily efficient, regarding both workflow and communication of information to other participants:

A1: *It makes it really easy to produce a lot of work for yourself that isn't necessary – like for instance you can do a couple of details or something of one area and that will cover a majority but sometimes we go in and cut details for wall sections all over the place to check stuff and they end up in the drawings and then you have to manage that drawing itself so it can add a lot of work – so you still have to know how to put a set of drawings together.*

(A1) was also still aware that what instigated this dialogue in the first place was the conviction that embedding information in a BIM tool early on in the process enables the automatic extraction of information such as cost and scheduling, and tracking project information for facility management purposes. For him, this meant that *"a lot of people know what Revit can do so they expect you to do it early"*, and introduced a conflict between raised expectations and the pragmatic perspective of "*getting the job done"*:

A1: *They say like oh you can get me an exact square footage number right off the bat – and I'm like well maybe we don't need to just quite yet – we can estimate, and for this one [project] we had an exterior wall schedule quantity schedule so we knew exactly how much brick and stucco we're using – once you tell somebody that, they expect that from you – so it's a good tool but sometimes it can make people's expectations really high – which is good but at the same time it's a lot of extra work that may not necessarily be done.*

4.3 The Intern/Designer

4.3.1 Background

(A4) is a young intern who had just joined the architectural firm for several months with very little work experience but a talented designer with a professional masters degree in architecture, a masters of science degree in historic preservation, and a good record in teaching design studio. To (A4), working at the firm is still like school to her. She considers practice as part of the education and sees a split between academia and practice. That was part of why she decided to go into practice for a while before going back to teaching. She came to the firm knowing that she had a lot to learn both about "*how to put a building together*" and about working with BIM tools, especially Revit, to be able to carry out the tasks required from her and cope with new technology.

(A4)'s typical day at work is a very busy one. She was not fully dedicated to the SG project, but as an intern she worked only 16 hours per week for this project, and the rest was split between marketing work and being dragged in other projects. Her typical day was usually full of continuous deadlines and assignments for different projects that can reach 10 simultaneous projects. Despite this load, she was assigned a significant role in the project. Most of the design and production effort was done by (A1) and her, in addition to (A5) who joined later on to assist because of her incompetence in using Revit. (A4) realized that because she was still new and not that knowledgeable in either the tools or the profession being in her first project, she had less "*weight*" and consequently less authority within the team. She describes her arguments and opinions as being listened to but opposed by (P1) most of the time because it was not her decision at the end. She also thought however that (P1) and (A2) valued her ideas and role in the project, or else they would not have assigned her responsibility of that part of the project. Figure 4.2 describes the main tools and representations used by (A4) in relation to the BIM base model.

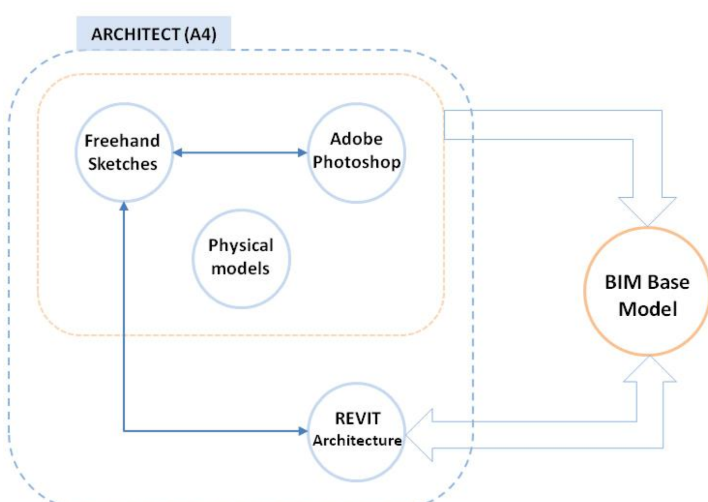

Figure 4.2. Relation between the tools and representations employed by the architect (A4) and the BIM base model in the SG project

(A4) relied on a combination of freehand and rendered sketches, physical modeling and 3D modeling. The sketches and physical models were used by (A4) mostly in the schematic phases of design. These were used indirectly by other members of the team who did the necessary modeling in Revit. As (A4) became more competent in Revit by time, she contributed to the model, although only in minor portions.

4.3.2 BIM as Enabler of Design Production and not Conceptualization

For (A4), Revit is more of a production and coordination tool than a design thinking tool. She preferred alternating between freehand sketches and physical models in the early design phases to express her ideas. By time she became more confident in using Revit and felt she could carry on her design in the modeling tool. She was more inclined to use Revit at a later stage in the design process and not for schematic design:

A4: *I mean it's probably good at the end of the DD to have the model - that would be good but until then I don't see the point of it.*

She still believed that this may be partly because of her incompetency with the tool and the struggle of dealing with functionalities of Revit that are not related to design such as model ownership and worksets. Furthermore, she thought she would be able to "*use it as a design tool*" rather than just using it at the "*execution stage*" provided that she learned more about the details of how Revit works. On top of that, she believed that because Revit forces practitioners to "*provide so much detail*" makes them "*fall into a trap*", where they are compelled to think about detailed information that is not necessarily available at early stages of design. This casts doubt on Revit as "*a valid tool for design*", in addition to its suitability across the phases of the project as a tool that is "*not for schematics*":

A4: *If we feel comfortable with using SketchUp or MicroStation or whatever in different stages of the project we should be able to do that – what bothers me is we need to use Revit from the beginning till the end – because I'm very sure that Revit is absolutely a wonderful tool starting from a certain point in the design process.*

Using a BIM tool only "*starting from a certain point in the design process*" was also essential for (A4) because of the need to "*improvise*". By improvising, she refers to the ability to develop workarounds within the tool to achieve a certain design task without being impeded by the rigidity of its functionalities and the associated steep learning curve:

A4: *What I find frustrating about Revit is the fact that you can't improvise because it comes – and I understand why – because any command comes embedded with a lot of information – so even if in drawing – if I want to arrive from point A to point B I can only do it in one way not like that – so that's what I mean I can't improvise…well there is only one way to do it in that certain condition for that certain drawing for that certain sheet for that certain view.*

This makes the tool limiting for (A4) in terms of possibilities and methods. Implications on decision making, design conceptualization and development fundamentally affect her appreciation of the tool and hamper the process of exploring design alternatives or reflection. Having to specify countless details and input a lot of parameters a priori forces her to think in a certain direction which she had not originally intended:

A4: *How am I supposed to have that knowledge – I don't even care if it's storefront at this point – I'm trying to compose the façade – I don't care if it's a piece of plastic right now – I don't care if it's a storefront – I'm going to assign it to be a storefront later if I wanted to – why would I have to decide it's a storefront knowing that it's going to cut in a certain way through the wall – that is a stupid thing because the more I decided it's a storefront it's going to lead me to certain kinds of design because it cuts in certain ways through the wall – so then where does that leave us? To have that detailed knowledge about the storefront and what the storefront does and know the limitations of it – you still need a vast amount of knowledge to treat this as a tool and improvise.*

4.3.3 Questioning the Sole Use of BIM tools in the Design Process

(A4) was nervous at the beginning of the project and felt out of her comfort zone with using Revit. She was always in advantage by drawing by hand, and was afraid that the tool would constrain her and manipulate her, like any other computer software. While she preferred sketching and was relatively novice with Revit, she repeatedly questioned the notion of exclusively using Revit in the design process, highlighting the importance of alternation between different tools and being able to make a pick that suits best not only her personal preference and familiarity but also the design phase, the thinking process and the nature of the design task:

A4*: Ok I have these 5 tools what tool am I going to pick that is going to help me best to create design that way and inevitably pick the tool that you are most familiar with so you won't be encumbered by not knowing the tool and being a slave to the tool.*

This notion of "*being a slave to the tool*" was a frustrating experience for (A4) because: a) the functionalities of the tool did not allow for much flexibility or breathing space in terms of conceptualization or reflection, and b) in terms of workflow and coordination, Revit was the sole medium for expressing ideas and exchanging information among participants. (A4), as a novice Revit user who was trying slowly to make her way and fit into place with the "Revit loop" among all team members, was continuously bombarded with phrases like "*oh it's a Revit thing*" and "*this is how Revit does it*", leaving her with very little room to be "*in control*" and use the tool to express her ideas:

A4*: I'm nervous about it because I'm supposed to have everything in Revit - I have no idea how to do it - and because I have no idea how to do it I'm tempted to stop designing and just build it in Revit – but I need to design it because it is not designed – it's just some masses – so right now I'm designing – of course I'm designing and then I'm thinking at the same time how am I going to have this in Revit.*

The fact that (A4) has to "*have everything in Revit*" was limiting for her, partially because she felt incompetent with the tool, but also because it was far more critical in terms of her thinking process. Revit for her was a medium to "*just build*" in and not to actually "*design*" in, and so being forced to use Revit exclusively throughout the project meant she was "*tempted to stop designing*". The representations that she could barely create in Revit were still "*not designed*", and so she had to: a) translate these representations to another medium external to the modeling tool, "*design*" and reflect through that medium, and c) "*build*" her "*designed*" representations again into the modeling tool. This continuous loop had many implications on (A4)'s thinking and perception process:

A4: *It doesn't make me think in 3D – not in 3D it doesn't make me think geometrically – when I said 3D I meant geometrically – I mean it is geometry because it's a wall but that wall has stuff inside – it's not a wall – it's not abstract enough – when I want to design I want a tool that is abstract enough so I can assign meaning to it…I want a wall to be as abstract as a wall – I don't want a wall that is either a gypsum board or this or this or that – I don't need that kind of stuff at design level.*

The notion of an "*abstract*" representation or medium in this description implies not only a desire to reduce complexity or amount of detail but also to liberate from the captivity of continuous decision making hurdles that slow down the process and cause frequent stops. There was therefore a struggle to "*assign meaning*" to these representations in the tool at any time later on in the process, and not have to define every single detail for every building element from day 1 in the project.

The captivity that (A4) recurrently expressed in terms of reflection and studying design alternatives, and the intricacies associated with even conceptual massing and slightly complicated geometry, forced her to relocate her effort in using other media (including freehand sketching, diagrams, or even other software tools such as SketchUp or Photoshop) as an overlay:

A4: *Unfortunately Revit doesn't allow you to study – with Revit you don't have much freedom creating all these shapes – I didn't even know how to make a stupid tilted plane and in the end I said it's just complicated and I was calling people that knew what they were doing and I said I'm just going to draw the whole thing – I'll print this and draw over it – I don't think you can fully rely on Revit which is a shame – not yet – but we all do this kind of stuff we do some massing in Sketchup or Revit then we do it in sketch then we photoshop then we do something else.*

The personal preference or the distinction in itself between Revit and any other tool or medium was not the ultimate goal for (A4); it was rather the ability to choose from multiple tools and alternate between them in a way that serves the purpose of the design:

A4: *I'm used to a certain type of imagery in design which is the sketch – and that's not more true to reality than stupid Revit is – than the stupid line is – they are more abstract*

– one looks prettier than the other – but I'm not sure one is more of a valid tool than the other.

Most of those media were "*not more true to reality*" than each other to (A4), as they were merely representations of a building, whether those representations were sketches, 2D drawings, renderings, or 3D building models. The significance to her in this case was using Revit as any other tool and giving it the same weight, instead of relying solely on it as the predominant software that all AEC participants must work within, and "*tossing away all the other tools*":

A4: *I wish we wouldn't toss away all the other software or all the other tools and have just one software be it Revit be it SketchUp be it anything else that we're going to use and that would be the only one – I mean I wish we could use Revit just as any other tools we are using and just to be one tool among many.*

This would avoid different participants from being *"dragged into this kind of thing where everybody is forced to use one software over the other*" and allow for using modeling tools such as Revit as "*a tool of design as valid as the others"*. Resolving issues related to interoperability and data exchange, according to (A4), should be of the concern of software developers and not designers. Therefore the idea of an all encompassing tool becomes futile:

A4: *I understand the reasons behind it but we're pushed into – I just want to have a choice – am I hoping for the next best thing to happen – for the next best software that encompasses all this – there is never going to be something like this – I mean let's face it – we're going to use this for this – this for that – this for the other one.*

To (A4) however, using multiple tools for conceptualization and production, and having an all encompassing tool are not necessarily mutually exclusive. They just need to be addressed and structured differently:

A4: *I used to be able to know how to draw a line in Photoshop for example – there are just a very few ways to do it and it's very limiting and I found my own ways to do it so I was limited by those two tools that I have – well then I discovered a while ago that you can do that in Illustrator you have all those 400 options to do it at a click of a button and some day what I was producing in photoshop changed because I was working alternatively so I could produce ten lines in a second – and because I could produce ten lines in a second it didn't become a frustration and I could start creating something out* *of those ten lines – so what I think maybe Revit… because I don't think striving for one – striving for the software – the one… I don't think it's achievable to have one software that has it all.*

The core principle here is making use of different functionalities from a "*suite*" of multiple tools or external representations, all of which satisfy the preferences of different designers, the best fit for each of the phases of the project, and at the same provide a coherent and integrated medium for information exchange:

A4*: Are we going towards a direction where everything is going to be unified? Are we going to have one software that is going to encompass them all? Because I already see the tendencies… so you have suites… that's some sort of unification… I'm looking forward for that time when I will be able to use one part of the suite for schematic another one for whatever.*

4.4 The Cost Estimator/Contractor

4.4.1 Background

(C1) is the in house cost estimator at the architectural firm. He holds a construction management degree and a professional career that involves about 27 years of experience, 10 of which were at a big construction company and 17 years at the firm. According to (C1), he represents the contractor's perspective in the firm, which implies not only making sure that the design proposed by the architectural team is within budget, but also being able to efficiently and accurately extract the information needed by a contractor. In other words, if he is not able to extract that information out of the building model, the contractor would probably not be able to either.

(C1) works on providing estimates and budgets for all the projects in the firm, with all its departments including housing and mixed use, culture and arts, education, science, and historic preservation. (C1)'s responsibilities are primarily in preconstruction, ranging from early pre-design budgets to detailed construction document estimates. In this project, (C1) worked closely with (C2) (an outside cost consultant) in the schematic phase and towards design development. (C2), being an expert chief estimator, represented a reliable second opinion and support person. In the subsequent phases of the project, (C2) was hired to continue the cost estimation and take off effort, as (C1) was pulled off the project to work on another large scale project.

As (C1) was the sole in house estimator and consultant within the firm, his arguments and opinions were highly important to the architectural team and other teams in the firm. He believes that most architects have the tendency to design with cost usually as an afterthought rather than an integrated part of the design process. Consequently, he was not confident with any quantity take offs from the architectural team, and he had to go through the model himself to extract "reliable" information. He was also responsible for coordinating estimates with the consultants, especially structural and MEP.

Figure 4.3 describes the main tools and representations used by (C1) in relation to the BIM base model. (C1) relied mainly on the On-Screen TakeOff construction cost estimating software and MS Excel spreadsheets to generate his estimates, especially in the schematic and design development stages. The estimating software imports PDF files extracted from the BIM base model. Near the end of the project, (C1) was undergoing a transition to more advanced estimating tools, and was testing the Innovaya visual estimating interface and Timberline software, which had direct interfaces with Revit.

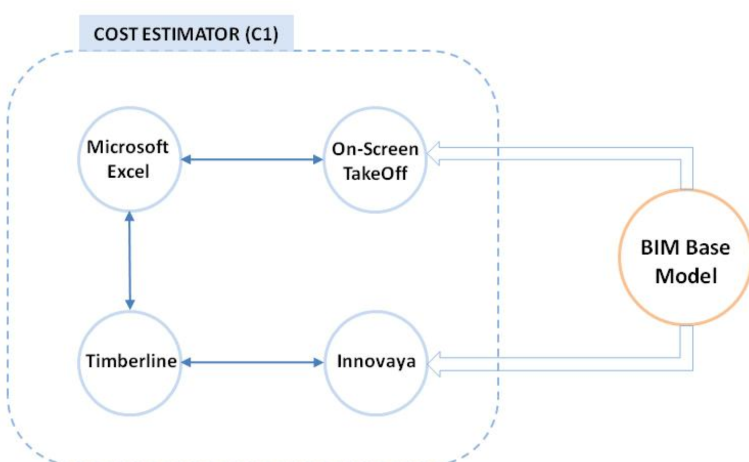

Figure 4.3. Relation between the tools and representations employed by the cost estimator (C1) and the BIM base model in the SG project

4.4.2 BIM as Overrated Process/Product

One of (C1)'s main concerns was that the so claimed automated process of quantity take off using BIM was a highly overrated process. At the same time, he thought that in order to achieve this level of automation, architects would have to draw every single detail and embed every single piece of information in the building model, which is unrealistic because they are never paid to do that. (C1) viewed BIM tools as being sold as doing something that they do not yet do:

C1*: I'm not assessing blame – if I'm blaming anybody I'm blaming the folks that are just selling this process as a be all end all.*

(C1) compares BIM to any new buzzword or approach in the AEC industry that is the "*latest greatest thing*" that everybody claims it is going to change the way design or construction is done. All AEC participants would then ask each other whether they were doing BIM or not, without necessarily knowing how useful it is for them, but just catching up with mainstream tools and products in the industry:

C1*: The example that I have always used is TQM – total quality management – which when I was working for a contractor everybody was talking TQM and this new approach – and everybody would ask when they sat down to meet do you do TQM? Oh yeah we do TQM – what is it you know? So BIM I think when it first came out I was thinking TQM.*

The real test, according to (C1), for assessing a BIM product/process is whether AEC practitioners are still using it a few years later, and that would indicate if it was worth its value or just a "*marketing thing that the folks that go to seminars and come in and do luncheons talk about*". The efficiency of the process is questionable for him as well because architects' models are still being reconstructed by contractors for their own purposes, and so the process and workflow is not as smooth and integrated as claimed:

C1*: The guys that are selling it to owners as this powerful tool I mean what are they doing? They are taking the architect's model and they are rebuilding it – they are rebuilding the model in a way that is useful to them – I mean that's not efficient.*

To overcome this overrated assessment of the process, (C1) prefers continuous conversation with architects and other AEC practitioners rather than a full fledged automation of the quantity take off and cost estimation process. This integration, which requires more of social interaction than tool functionality development, should produce reasonable, reliable and efficient results according to (C1):

C1: *In theory we should have this dialogue between myself and the designers – the people that are drawing it – to make sure that we're staying within budget because we will establish a budget early in the process – the challenge that I have with architects is that most want to design – as an afterthought usually is the cost, thinking more about design and less about what it costs – until they are actually through with the design then they start figuring out what it costs rather than sort of integrating – because once it's done and we find out it's over budget then you still have to redesign – so the idea is to keep one eye on cost and one eye on design as you are designing to make sure that you are designing within budget.*

4.4.3 Trusting Analysis Results from the Tool

(C1) and (B1), the BIM manager at the firm, were undergoing a transition process during the project, moving from the OnScreen cost estimating software, which relies on pdfs of the building model, to automatic quantity take off using Revit, Innovaya and Timberline. However, (C1) was not that confident in this automatic cost extraction process, and he believed that there was some sort of disconnect in how cost information is extracted from Revit and whether or not it was useful to him from a costing standpoint:

C1: *We took those Revit schedules and tried to make them reasonable and exported them into Excel to produce a spreadsheet that had information that I needed or values that I can manipulate to feed into an estimate but it just took a lot of effort and we realized fairly quickly that what we were having to do with these Revit schedules was time consuming and we were probably re-inventing the wheel doing that.*

Some of the cost-related information extracted through Revit schedules was fairly trustworthy for (C1), including count items such as the number of doors, windows and other quantities. He found count items to be the most reliable since there is no "*subjective*" component involved, although some subtleties in the tool could introduce some risks:

C1: *Count items would be the low hanging fruit but there is still the risk of a group of doors being drawn off to the side or torn off on another sheet or something like that and they get to be included in this quantity.*

The exported schedules however often lacked certain attributes or other pieces of information, such as units of measurement or type of material, that were necessary for (C1) to conduct his calculations and estimates. This forced (C1) to go back to the drawings and make frequent checks instead of relying on automatically generated figures:

C1: *Let's see if I can find a good example – precast entry stair 1 – precast entry stair doesn't really tell me what I need to know – so you are always going to have to – even if you got a schedule or you are exporting commodities from Revit to wherever then you are still going to have to go back and look at the drawings to see.*

These figures were mostly ambiguous or abstract, and (C1) had to make many guesses and assumptions. He thought the architects were more capable of providing those assumptions than he was, since they were more involved on the design side:

C1: *What I think the way that it should be done is rather than me making those assumptions, they are more qualified to make those assumptions than I am in some instances.*

As (C1) was receiving mostly abstract and vague information, (C1) had to go through the tedious process of checking the drawings to make sure his estimate is built on credible data. He often found missing data or parameters related to some building elements, something which was extremely frustrating especially when he was scrambling trying to meet a certain deadline. This then was not a problem related to the tool only, but shows that the architectural team was not fully or correctly representing the information in the BIM model. This occurred particularly in schematic design, where they were reluctant to make critical decisions. All these factors combined affected (C1)'s level of confidence in the quantity schedules generated by Revit:

C1: *Let's say that you could print Revit spreadsheets and quantities and everything – just print them out and hand them to somebody – the problem with that is that you are assuming that the architect is drawing everything correctly and everything is labeled as it should be and no duplications and all that stuff and Revit just grabs all of those quantities and puts them in a spreadsheet and there you go.*

This skepticism in the results coming out of Revit reflected a desire from (C1) to be always in full control of the inputs and outputs of the cost estimating process without being misled by unreliable data. He was not sure he could trust any data that he had not originally tabulated, examined or gone through in detail. Using quick comparisons between self-generated estimates and others generated by Revit, he came to trust more the self-generated ones, not only because he initiated them, but also because he felt in control of the process of reviewing and keeping track of the estimate along the phases of the project:

C1*: Let's call this an OnScreen schedule and this is a Revit schedule – I mean just from looking at that versus that I can see the difference – but the good thing about this is that I'm the one that named all these.*

4.5 The Landscape Designer

4.5.1 Background

(L2) is a landscape architect holding a landscape architecture degree with 7 years of professional experience, 2 of which are at the civil and landscape firm. (L2) represents the engineering perspective in the landscape design profession, which implies not just *pretty picture* conceptual design work, but primarily storm water design work and infrastructure design. (L2) is project manager and works with a senior engineer as well as a CAD production group. His main role is the conceptual design work and getting the engineering work done. Although (L1) was the primary contact for the project in terms of communication with the architectural firm, (L2) was heavily involved in coordinating the landscape design aspect of the project with the architectural team. His opinions regarding selection of outdoor materials, planting, and hardscape were significant in the design process, especially while interacting with (A4) who was responsible for landscape coordination in the design development phase of the project.

In terms of coordination with the architectural team and AEC consultants, (L2) emphasized throughout the project phases that all teams were working inside the building while he worked on everything else outside the footprint of the building, including utilities and civil work, implying a sense of separation of roles and work mechanisms. This was evident in the frequency and nature of communication between the civil and landscape team and the architectural team. There were many dormant intervals between the conceptual phases that featured physical meetings and informal communication, and the final construction documents phase. (L2) worked quite separately on his own calculations and assumptions based on the information he got at the beginning of the project with respect to utilities (land survey) and building location (from the architectural team), and then proceeded with minimal communication from that point onwards.

Figure 4.4 describes the main tools and representations used by (L2) in relation to the BIM base model. (L2) used, in addition to freehand sketches for conceptualization, some analysis tools such as HydraFlow and Civil 3D. These had direct interfaces with AutoCAD which was the main production platform. Interaction with the BIM base model was only through DWG files generated by AutoCAD and its civil add-ons, and embedded into the model to show updates of the project 2D site plans for the rest of the practitioners.

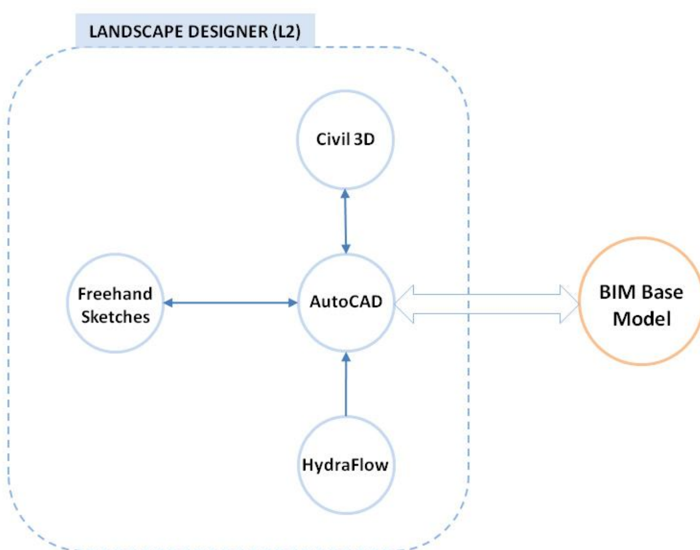

Figure 4.4. Relation between the tools and representations employed by the landscape designer (L2) and the BIM base model in the SG project

4.5.2 BIM as Domain Exclusive Tool

To (L2), none of the 3D aspects in the civil and landscape conceptual analysis models need to be communicated to the architectural team unless they need it for presentation and rendering purposes. He makes a clear distinction between the nature of representations in the architectural domain and those in the civil and landscape domain, and consequently the tools employed in each. Comparing "*flat planes*" to "*building structures*", he describes these planes as being perceived by architects as simple "pictures" for the most part "*once they get outside of the building*". This makes them "*rough in*" these planes as 2D elements such as parking lots that do not imply complex geometry according to his description:

L2: *Usually we don't have anything that complex – I mean the base thing – the three dimensional item that we have is earth works and we're basically making a three dimensional model of it – the computer sees it as a three dimensional model but rarely do we ever put it into an aspect where you are looking at a three dimensional model.*

So there still is a 3D component to the representation, including terrain modeling for example, but he describes the product coming out of the architectural domain as completely separate, where he uses the "*footprint of a building in doing everything exterior to it*" and the architect uses the "*footprint going in*". In these separate areas of work, there is also an implication of a "*flatter*" nature of the drawing, where terrain differences can just have some intermediate breaks or only five or six inch increments, but inherently "*looking quite the same*". Given this discrepancy in complexity between the civil and landscape domain and others, (L2) sees no need for such a tool:

L2: *If their objects are three dimensional in the interior of the building they are totally useful for them – I don't have any need for it – period.*

This implies an inherent burden having to model elements three dimensionally. There was no need according to (L2) to represent most elements three dimensionally, let alone communicate that information in a BIM model to other AEC participants. He understands why architects need 3D modeling functionalities for the elements in their domain, and at the same time argues that they can work without having to use his terrain models because they are not of any use to them:

L2: *It's a different aspect because when you are in a building you got a lot of items that you are dealing with – outside the building we have asphalt, we got trees, we got terrain – you got 3 or 4 or 5 or even 10 items – it's a lot simpler aspect when you get outside of the building versus inside when you got a lot of product that you are having to put into a building.*

(L2) would therefore receive BIM model updates from the architect through the project server, but the only form of communication between him and the rest of the consultants was through occasional updates of the 2D site plan. This complete separation in nature of representation also extended to include separation of process, where (L2) performed the landscape quantity take off process for example independently from the architectural team and used AutoCAD for basic counts. For him, the take off process is very basic and simple, and "*not as complicated as counting 3000 urinals or 200 sinks*".

4.5.3 The Need for a Separate Suite of Domain-specific Tools

(L2)'s interaction with tools in this project involved a combination of 2D and 3D representations. The main domain specific tools that he used were AutoCAD Civil3D and Hydraflow, which are primarily used for all pipe work design, storm water and sewer design. The Civil3D package has a 3D component to it and some 3D aspects of earth work as it creates terrain models, but its output is 2D plans, which are then passed on to the architectural team in the form of dwgs or pdfs for coordination. Whether the software used is StormNet, PondPack, Civil3D or Hydraflow, (L2) has some basic requirements in the tool he uses to conduct his basic calculations. He prefers Hydraflow because it is integrated with AutoCAD, but he has some fundamental needs:

L2: *You take a certain water flow, you tell the computer that this is the pipe that is entering and this is the slope the pipe is running at and this is what the pipe is made out of – you got a certain roughness coefficient and the size of the pipe telling you that this amount of water will fit through this pipe – if it backs the water up or if it won't go through the piping, resize the pipe or make the slope steeper or change the product.*

However he pointed out that fact that these needs, while satisfied in the software packages he uses, especially Hydraflow, it is a tedious process, where the user has to input the variables manually:

L2*: You design in one but you have to manually change the design drawing – and when I say manually change it it's just a matter of punching in the parameters in the design drawing – tell it instead of an 18 inch pipe drawing we're using a 24.*

(L2)'s expectations for a better tool all revolved around the idea of a "*separate*" but "*seamless*" product which would not necessarily be integrated with other domains because of the discrepancies in representations but allow for the enhanced feedback and automatic adjustment of design elements upon the alteration of the input parameters and settings:

L2*: If you would change a pipeline and make it bigger or have a different slope then it would automatically change that in your profile for your CAD drawing, where you have a pipe run and it shows all your boxes and so forth and structures – well you also have a theoretical design over here and it has just a series of numbers – your basins and all your factors and parameters – and let's say change something over there then it will automatically change your design drawing.*

4.6 The MEP Coordinator

4.6.1 Background

(M2) is a registered electrical engineer with 27 years of experience in electrical design. He has worked in a variety of offices and in different types of projects, and has been working for the MEP firm for three years. (M2) brings a lot of experience in the firm, both with regards to electrical and lighting design, and MEP coordination. The MEP team was a mixture of new engineers under training, engineers new to BIM, as well as expert engineers. The fact that he himself was an expert engineer but less technology savvy presented a challenge. He managed however to achieve a successful coordination and communication process with the help of his co-workers in addition to an architect who was hired to help with Revit coordination.

(M2) was the lead electrical engineer as well as project manager for some projects including the SG project. He was the primary contact and project manager for the SG project and responsible for scheduling and overseeing the electrical design on all projects that take place in the MEP firm. His role was to oversee the electrical design as well the entire coordination of the entire mechanical electrical plumbing design with the architectural team. As the MEP coordinator between mechanical, electrical and plumbing, all the departments reported to him and communicated to him the latest updates, issues and problems.

Figure 4.5 describes the main tools and representations used by (M2) in relation to the BIM base model. (M2) coordinated the work of the electrical, plumbing and HVAC departments in Revit MEP. This file was the main interface to the BIM base model. Each department used its own tools to interface with the central Revit file, such as Visual for the electrical department, Carrier HAP for HVAC, and AutoCAD for plumbing.

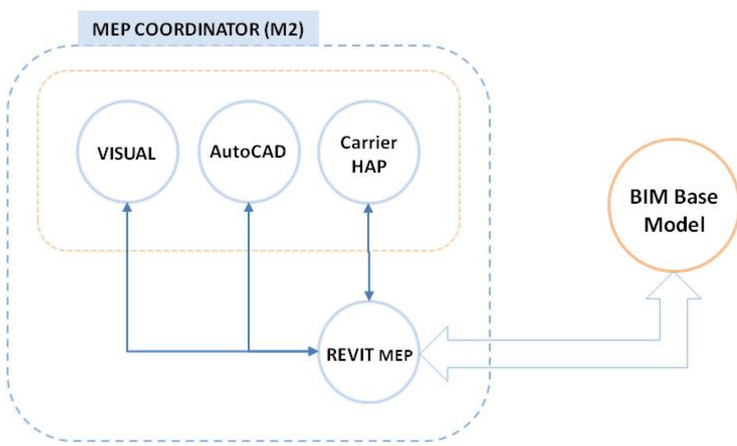

Figure 4.5. Relation between the tools and representations employed by the MEP coordinator (M2) and the BIM base model in the SG project

4.6.2 BIM as Frustrating Learning Experience

Working in BIM for (M2) was a new experience, with this project being the second Revit project. It was a learning process for (M2) and the MEP team, and a mostly frustrating one. The firm was in a transition phase where some projects were done in

Revit and some in AutoCAD, but (M2) sees AutoCAD as still being the predominant or preferred among most engineers in the firm:

M2: *They [engineers] are so used to AutoCAD and the pace that they can move designing and developing our product on AutoCAD that it's frustrating to move slow and relearn processes in Revit.*

(M2) believed that MEP engineers would start adopting Revit on a wider scale only if MEP modules are more developed as he claims they are within the architectural environment. He thought that architects and MEP engineers had a different experience regarding BIM tools in general:

M2: *If we could get to the point to where Revit works as well in the MEP environment as it does in the architectural that would be a wonderful tool.*

As part of the gradual transition to BIM, there were a lot of lessons to be learned and steps to go through, in spite of the general resistance by MEP engineers. This meant for (M2) migrating from readymade CAD libraries and also slowed down the design process due to the high cognitive load:

M2: *We're really crawling – and we were watching it[Revit] for some years because the architectural community has been using it for a while but the MEP modules have been slower to develop – and we're still finding that there is very few manufacturers on board yet with [Revit] families and when we do bring in some of those we have interaction issues – they don't function properly within Revit and they lock up our model and there is just issues sometimes – so the whole MEP industry is just starting to pick up that first step.*

(M2) was willing to take additional steps to make this transition and took measures to "*be on the leading edge of this learning curve*" because he could see the potential of BIM in issues such as "*designing within the 3D space that the architect models*", making sure that all AEC participants are not "*trying to occupy the same space or that this pipe isn't going to intersect this duct as it goes through*", or figuring out the most cost effective ways to design or based on building model material estimation. His concerns though were mainly related to the competency of computing power in the case of extremely large building models, in addition to the level of maturity of BIM tools:

M2*: It's a maturity thing – is how does this design tool matures and how do we as a team decide how things happen because conventions are being developed – I mean we've got things that are expected in AutoCAD – 20 some years we've been using AutoCAD right? Early mid 80s when we got our first CAD system – so that's what like 25 years – so that tool had a long time to develop – and you know BIM and Revit and all that is still in its infancy.*

4.6.3 Addressing Domain-specific Requirements

Some issues were really problematic in Revit and took longer than (M2) expected such as linking information from Revit from and back to MEP analysis packages like Visual, AutoCAD and Carrier HAP, integrating manufacturing parts and Revit families for coherent design, constructing libraries of 3D details instead of 2D CAD details, and the overwhelming amount of setup and unnecessary detailing that had to be done at the front end to achieve only very simple commands. "Visual" is a software package that (M2) prefers for lighting photometric calculations because of its graphic component, flexibility, ease of use and integration with tools like AutoCAD. Although this serves the purpose of incorporating the analysis package with existing CAD libraries, there is very little integration with BIM tools such as Revit. There is therefore a strong chance of redundancy, where the model has to be built again in the analysis package to perform the photometric calculations:

M2*: For the most part it's 2D – there is a 3D element – we can do some simple renderings and shading within Visual but what isn't there yet and really is assumed to be functional and we hope within Revit is that you actually build your 3D model your building – and then that building is inside your calculation software – we can't pick that up today as a 3D model and bring it in – we have to build it in Visual also.*

This introduced a burden to (M2) where there was always a clear cut distinction between a "*drafting*" tool and a "*design*" tool, which becomes very time consuming due to the fact that the input data is never shared among the two tools, but rather has to be entered manually and constantly in each tool:

M2*: We have our design software or our drafting software but then we have to take that information and model it into some other software – use that output then to size systems* *that we then put back in – we're back and forth in and out between different systems – we can't share the same input data.*

(M2)'s expectations for better integration entailed embedding input data in the BIM model, rather than going back and forth between multiple tools, in order to acquire immediate feedback along the process and adjust the design within the feedback loop:

M2*: I know that to use Revit within HVAC to run your HVAC load calculations and to determine what your heat loss is so you're scanning windows and determining how much air conditioning or heating you need to put into a space – if that's all integrated in your model eventually it saves us time because you enter it one time and then you use that same model as your input.*

Software integration problems were not the only source of frustration for (M2). The lack of integration of BIM tools with manufacturers' engineering parts was a major problem. Arbitrary 3D representations of MEP fixtures within the architectural 3D models had to be constantly replaced with engineering models from manufacturers. (M2) had to search for and download these to the model because what the architect provided him with does not have the necessary connection points. At the same time, the automatic features in Revit do not allow him to just tell something to connect to a specific point or piece of equipment. Those features are not usable when the model does not offer any connection points. (M2) then had to look for similar engineering models and put them in the model as placeholders that do not reflect the actual parts:

M2*: It's the fact that we don't have the information available – you would really like to go to the manufacturer's webpage of the product you would like to use and pick up their [Revit] family and put it in to your drawing but it's probably not available then you search for something that is similar and you use that as a placeholder so you know we're making due.*

In one of the labs in the SG project for example, the architectural team was only able to find a generic type of hood. This hood is handled very differently from the specific hood that (M2) meant to use, as it required a different kind of exhaust and was more regulated, but it was the only available engineering model, and so required some more coordination with (M2) to make sure the specification data embedded in the BIM model was placed correctly:

M2: *We expected to see a bio hood and we saw a prochloric acid hood on the drawing……it was in the model and it looked very similar but the tag on it was a prochloric acid hood – there should be some inherent things that happen automatically because we're doing Revit but because of the information available to all of us that's just not working – it actually caused us to have to do a little more coordination than typical because of that.*

This lack of suitable information concerning engineering models was augmented by the burden imposed by Revit, which forced (M2) to connect for example a pipe to a specific location on a certain piece of equipment. He had to always first "*fill*" the BIM model with the engineering models and equipment that were not readily available by the architects, rather than just showing all electrical conduits, piping and ducts to an arbitrary location:

M2: *You have to have that point – it doesn't exist – you have to create that point – and before we used to just bring it to the location and more so with notes or with symbols that mean things we could tell them what type of connection they had – and if we were within a few feet it was ok because the contractor filled that gap – today the model brings it to that point and shows really all the fittings to that point – so it's just so much detail and the Revit software wants that detail – and it kind of doesn't want to move forward if you have it or you don't fill it.*

4.7 The Structural Engineer/Modeler

4.7.1 Background

(S2) is a young engineer holding a masters degree in structural engineering. He came straight from school after completing his degree to the structural firm and has been working there for about 3 years on several projects. Being a young engineer, (S2) was going through a learning and training process, especially with learning Revit which represented a challenge to him, as he was assigned to be the sole Revit user on the SG project, and it was his first Revit job.

In terms of his work experience, he was the lead engineer on a number of projects, including the SG project. These were mostly structural steel construction projects. He worked with (S1), the project manager and under his supervision. He also relied on (S3) concerning technical support with Revit. With regards to collaboration and coordination with the architectural team, (S2) participated in all the meetings and was in charge of all the production work of handling the Revit model and structural modeling.

Although (S1) was the primary contact for this project, (S2) had interaction with the architectural firm as well, but his interaction was in a more detailed sense, along the lines of figuring out with (A1) for example the dimension of a slab edge from the column grid at a specific floor level in a specific bay to ensure coordination. (S1) however was more involved in high level issues, such as discussing with (A2) and (A1) where the transition may occur between stucco and brick as a façade material and how that interfaces with glazing and where miscellaneous steel is needed.

Figure 4.6 describes the main tools and representations used by (S2) in relation to the BIM base model. (S2) used Revit Structural as the main interface to the BIM base model. For the structural analysis and calculations, he used both the RAM structural analysis package, in addition to AutoCAD for simple detailing.

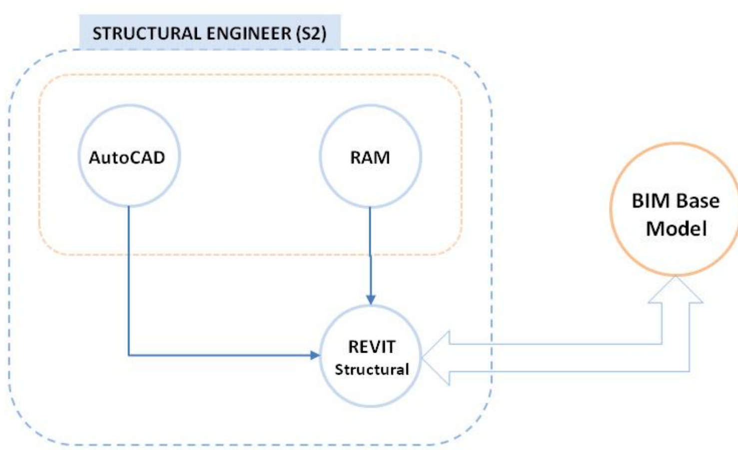

Figure 4.6. Relation between the tools and representations employed by the structural engineer (S2) and the BIM base model in the SG project

4.7.2 BIM as Daunting Workflow

(S2)'s interaction with tools in this project was basically a learning experience with using Revit. For him, it was a complete shift from tools he was used to like AutoCAD. He thought that there would be a learning curve in general for the structural firm and that it would take him in particular a little bit longer to adapt to a new mindset:

S2*: You go from an AutoCAD mindset and then all of a sudden you have to go to a Revit mindset just as far as the functions – so the best way to do it is do a Revit job and then do another one.*

For (S2), the learning curve was a steep one, where the complexity of the interface of the BIM tool was totally unlike any other he was used to in his earlier experience. He still thought that the outcome of the tool would be more rewarding because of its accuracy and efficiency:

S2*: It's completely – I can't translate any of it to what I learned – you know like AutoCAD – it's completely different – just works differently and the commands and stuff are different – and I'm finding that I think the end product will be better but I think it takes longer to produce drawings than – at least it seems that way now since it's my first Revit job but I think that's normal going to any new system to produce drawings.*

One of the main concerns throughout this learning process was the process of replacing all CAD libraries and typical details with Revit families and details. Being out of the norm of practice for (S2), this was a time consuming process where all details had to be created from scratch, especially since the SG project was his first Revit project. However, he still thought that the tool was promising, and believed that the best way to learn the tool functionalities and become accustomed to the workflow was to "*get tossed in it*" rather than doing tutorials for example but not getting a Revit job for some months.

4.7.3 Incompatibilities between Modeling and Analysis Tools

(S2) was hoping for a smooth data flow between RAM (the tool that he uses for structural analysis and is proficient with) to Revit in order to align the modeling and analysis processes together. On receiving the Revit base model from the architect, (S2) would (a) create a RAM model that represents the conceptual structural model of the building, (b) translate and abstract the architectural model into its structural counterpart model elements in RAM, (c) perform his structural calculations and analysis in RAM, (d) propagate the analysis results (e.g. depth of beams, cross section of columns, etc.) into the Revit model, and (e) send the model back to the architect for further updates.

Both (b) and (d) involved a time-consuming manual process, where (S2) had to – in case (b) – look at the architectural model elements in Revit and manually create structural objects in RAM from scratch, and – in case (d) – look at the structural analysis results in RAM and manually input dimensions and sizing back into the Revit model:

S2: *It just takes a lot longer because you are sitting there and you have your RAM model up on one screen and your Revit model on the other screen and you are going beam by beam – column by column – brace by brace on each.*

This was a very tedious and frustrating process for (S2). But it was neither directly related to his lack of expertise in using the tool nor was there a deficiency in linking RAM to Revit through a direct interface. There was however a burden associated with managing the propagated RAM structural elements into Revit to the extent that it was easier to just represent the analysis results in the form of manual input of parameters in Revit:

S2: *One of the guys in the office was saying that you could export from RAM into Revit but he said that there's too many kinks – he said that once you export from RAM to Revit it takes just as much time to go and clean things up just as it does to do it from scratch – just to do it by hand so to speak – so that's something that they can definitely improve on.*

This was a major source of frustration for (S2), as he expected that the internal representation process and the team-team coordination process would involve smoother flow of information. While (S2) relied mostly on (S3) for technical support and did not know "*100% of all the ins and outs of how Revit works*", his main aspiration was an efficient information exchange process between structural modeling and analysis packages.

S2: *Going from RAM to Revit as far as building the models they work independent of each other right now…it would be nice if you could export it and everything work – I don't know how if the RAM folks and the Revit folks are working together to try to make that happen – it would be nice if they would – it would make both of them better.*

4.8 The Audiovisual/Interior Designer

4.8.1 Background

(V2) is the director of audiovisual design at the audiovisual firm. He has more than 20 years of experience in the audiovisual industry, 8 of which were at the firm. He oversees the engineering department and is in charge of engineering and design, and so his role is more of a management role. He does not do any of the drawings himself in the firm, but allocates resources and plans how CAD tools should be incorporated to address audiovisual related issues. Although (V1) was the primary contact for this project and (V2) was in the background and not heavily involved in this project, (V2) had a strong position in terms of making the transition in the firm to adopt BIM as their method of work and delivery. According to him, this push, an unusual one for an audiovisual firm, was usually resisted from architectural teams, and in most contractual agreements they were just asked to provide 2D CAD drawings in their exchanges with AEC consultants.

Figure 4.7 describes the main tools and representations used by (V2) in relation to the BIM base model. (V2) used AutoCAD to interface with the BIM base model, although he was undergoing the transition to Revit. For acoustical analysis and audiovisual calculations, he used both the EASE acoustical analysis software and AutoCAD.

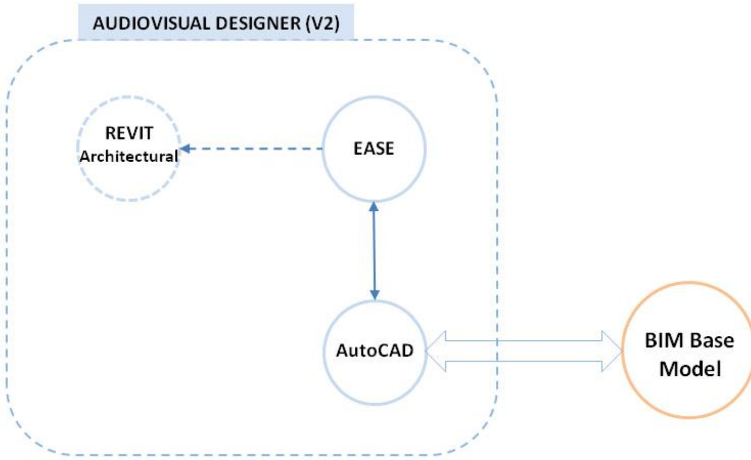

Figure 4.7. Relation between the tools and representations employed by the audiovisual designer (V2) and the BIM base model in the SG project

4.8.2 BIM as Fully Integrated Process

What was interesting about (V2)'s method of work is that he seemed to adopt unique approaches, not those of a "typical" audiovisual firm, regarding both tool (applying BIM in practice) and profession (acoustics and audiovisual design). He was an expert Revit user and was willing to integrate BIM in terms of both 3D visualization and information exchange with AEC consultants, but was occasionally getting pushed back by architectural teams. At the same time, during the internal analysis process within the firm, he focused on simulating the 3D space environment and embedding information and calculations regarding distances, heights, sight lines, and 3D space configuration into the BIM model. He believed that this would allow for a more robust and meaningful building model that incorporates these calculations and makes other consultants aware of the audiovisual design decisions.

The approach adopted by (V2) stems from his perception of the audiovisual discipline, where he saw himself closer to interior design rather than a "typical" engineering oriented audiovisual designer. This dissociation from the electrical engineering discipline was not necessarily in the audiovisual product according to (V2), but in the methods and thought process that he uses to arrive at the product:

V2*: A lot of A/V consultants are using the MEP but we're not an MEP – a lot of them are and we don't have a particular emphasis of conduit fill and things like that – a lot of those guys are on that side and we're more on the interior design side – if we have a discipline to be closer to I think we're closer to interior design than we are electrical so [Revit] Architecture makes more sense to us – and in terms of using any data to create things for our clients they wouldn't be so electrically focused – we would do power conception models and things like that but just as important for us is modeling the lighting and things like that.*

To (V2), that justifies using Revit Architecture as a software package, because his main focus is studying the 3D physical configuration of spaces and building his own model of where conduits and connections would go based on his calculations:

V2*: We're more concerned with space planning I think than really where the specific conduit goes – we just know we need this much conduit from here to here – the path is significant but what is more important to us is how the room lays out – how everybody in this table has a good view of that, and that's important to us – so we're more in tune with that – we use more brain power figuring that stuff out than we do anything else – so it just makes a little more sense for us to be on the architectural side.*

(V2) used the Revit Architecture package for these reasons but he was also concerned about incompatibility issues among different software packages, as these would cause a disconnect in the process of exchanging necessary data from one package to the other:

V2*: [Revit] MEP had a lot of metadata that you couldn't get into [Revit] Architecture at all and basically it was used to count things and all that so they didn't think it was necessary but you know the architects aren't using [Revit] MEP.*

Another issue with BIM tools, according to (V2), was the adaptability of the tool to the nature of representations that the audiovisual discipline requires, where *"a good portion of the final deliverable is schematic in nature and there isn't really a schematic component to any of the BIM products"*. This implies that the layout and infrastructure drawings can be represented in Revit and not the *"schematic portions of the design"*. In spite of (V2)'s desire to integrate these representations in a more structured environment within the BIM process, he believed that it would be probably better that he just "*stay in the CAD world*", take the model and make "*backgrounds*" from it without "*contributing* *to the noise*", if the AEC participants are not willing to sit down and take practical measures for this integration:

V2: *We need an agreement – we need the meeting to happen early where there is an agreement that says you're this detailed at this stage and you create this detail at this stage and what the deliverable expectations are and all of that has to be planned out.*

4.8.3 Integrating more Metadata among all Participants

(V2) had pushed the audiovisual firm to migrate most of the CAD block libraries to Revit families and was ready to interact and communicate through the Revit Architecture software. He experienced however some push back from other AEC teams, and did not sense that they had interest in exchanging BIM models. The architectural team, especially (A1) and (A2), asked that the audiovisual firm provide 2D CAD drawings and not BIM models, arguing that the architectural team will import CAD models and take care of inputting the data that they need into the BIM model. (V2) saw this type of exchange of data as a mere coordination effort that was not quite different from actually going to the architects, coordinating, and marking up the model on paper:

V2: *All we'll do is coordinate, and our physical drawing release will still be CAD because most of the people we work with are just not – are just pushing out in Revit just really getting into it – and first of all what we would do is maybe drop equipment in – really insignificant to them at the moment – we would mark our places where they would put boxes and things like that – so it's more of a coordination effort.*

This was frustrating for (V2), not only because it was an inefficient process but because he thought there was much potential in using BIM that is not fully captured by architects or consultants. For (V2), they do not make utmost use of *metadata* but rather focus on catchy renderings or images. This metadata included aspects such as the 3D space configuration and the relation of projection screens to conference table locations:

V2: *Everybody just says well look just go through stuff we'll throw it in there and then we'll end up with something that looks right but really the data is not real, and so what do you have? You just have a pretty picture – and not so pretty because of the data you can't put the level of detail you had put in to a 2D drawing and a 2D view because the level of detail that you would put in to make something look pretty on paper will crash the model because of all the other information there.*

The analogy to a *pretty picture* that *looks right* but is *not real* lies at the core of the notion of inaccurate deployment of metadata highlighted by (V2). He extends this notion to criticize the catchy renderings generated by architects that do not take advantage of the full capacity of the tool:

V2: *I think when you see a lot of pretty pictures coming from an architectural firm to me that says they are not thinking on the deep end here – what is really going on is they found a way to use the software but they really aren't using the software the way they should be.*

What (V2) was aiming at was integrating data from domain-specific calculations into the base BIM model so that the architect and other teams can benefit from those underlying calculations and assumptions. (V2) used a combination of the EASE software, Revit Architecture and a lighting analysis software to do lighting and acoustic modeling. He was able to extract information concerning sight lines, lighting, and geometrical relations between projection screens and 3D physical configurations. Although he could not integrate that information into the base model, he continued to use the same tools to "*do the math*" whether he was going to use them to "*deliver or not*":

V2: *We spend an enormous amount of time dealing with physical placement of things – very important where a connector goes – a lens throws – the viewing angles that people can see…and also the lighting is very crucial – in distance learning and video conferencing it's very important that presenters are lit directly and that the light isn't passing on to the screen – and so lighting models are very very important.*

4.9 Discussion

This chapter presented the different types of personas identified in the study with the most salient characteristics pertaining to the main question of the research. The archetypes presented in this chapter, which include representatives from each of the participating disciplines, included the expert modeler, the intern/designer, the cost estimator/contractor, the landscape designer, the MEP coordinator, the structural engineer/modeler, and the audiovisual/interior designer. These archetypes covered a wide variety of issues and themes, such as the effect of background experience and expertise (including both tool proficiency and work experience), the individual learning process and learning curve for each of the participants, understanding the needs of other disciplinary participants, the intellectual and cognitive cost of the implemented tools, the incompatibility that exists among computational tools, the individual preferences of tools and representations in practice and the affordances of these tools, and the context and conditions related to the general transformation to BIM in practice.

One of the major observations regarding the identified personas is related to their sense of belonging to *disciplines* versus *communities of practice* (Wenger, 1998). From the "nebulous user" perspective, the participants mentioned in this chapter represent solely their disciplines; for example (A1) and (A4) are both architects, and perhaps (C1) could be seen as belonging to the architectural domain as he resides in the architectural firm. All the other personas would be seen then as belonging to their specific engineering disciplines, or are often just referred to as AEC engineers. This discards many of the nuances related to the needs, expectations and goals of each individual participant, rather than what is just known to be an engineering viewpoint or framework. Although this chapter involves individual stances of participants rather than their interactions, it sheds some light on the *membership* of those participants to different communities of practice.

For instance, (A1) is essentially a *member* of the architectural community, being part of the architectural team, and perhaps more specifically to a community of project architects. More importantly however is his potential membership of the community of BIM modeling or expert modelers, with the expertise and background he brings in to the team. (A4) may be seen as a member of the community of architectural interns, but may be seen in the context of her work in the firm as belonging to a community of *skilled* designers or novice BIM users. Coming from the *academic community*, she brings a lot of expertise in that regard to the *professional practice community*. (C1) represents a community of estimators besides the architectural community, but also can be seen as a member of a contractors' community. (L2) represents a community of civil and landscape engineers, but also belongs to a community of non-BIM users. (M2) is a member of an electrical engineering community, senior MEP project manager community and also an MEP BIM user community. (S2) is a member of the structural engineering community, but also part of the novice BIM user community and the structural BIM user community. (V2) represents a community of audio-visual designers, but also seems to belong to the interior designers' community and the community of expert BIM modelers.

This *multi-membership* of different and overlapping communities establishes a broader spectrum of perspectives, background and expertise, and a wider space of interaction and communication of information among participants. With participants belonging to different communities and wearing different "hats", whether within their disciplinary interaction or interaction across disciplines, a potentially richer space of communication of ideas and exchange of design information is formulated. As seen in the SG project, community membership is characterized by different relative weights for each participant according to their individual perspectives and needs. (V2) for instance can be seen more as a member of the expert BIM modeling community than the audio-visual design community or the interior design community. His membership in that community basically shaped his participation and role in the project, his viewpoint about the role of the BIM base model for all participants, and his expectations as to what type of information needs to be integrated in the model. Similarly, (C1) can be seen more as a member of the contractors' community. His expertise in preconstruction and his previous experience with similar projects and with contractors and other estimators shaped his approach toward estimating and the level of confidence with the analysis results coming from the BIM tools. (A1), being a member of the expert BIM user community, was more focused on using the capabilities and functionalities of the tool to the maximum, both during the schematic design phase within the architectural team and during the coordination phases with the consultants.

These weighted multi-memberships shaped the position of each of the personas towards BIM as a tool or process. Their view of what BIM was varied widely. While (A1) was able to use the BIM base model for design thinking and reflection, (A4) for example could only use it for production, as she was not experienced enough with the tool functionalities and belonged to another school of thought that preferred a certain level of ambiguity at early stages of design, represented in sketches and other representation media, to the constraining level of precision of the BIM tool. (C1) preferred a tool that can give him enough control over the process of estimating and therefore saw BIM, which relies mostly on automated extraction of information, as an overrated process that only makes the estimating process more of a black box that does not enable a transparent interpretation of the design-cost feedback loop. (L2), being a non-BIM user, emphasized the fact that BIM was domain exclusive and did not offer enough integration with the tools he used for civil and landscape design. (S2), (A4) and (M2), being primarily novice BIM users, saw BIM as a daunting workflow and exhausting learning experience, while (V2) who was an expert BIM user but did not use Revit on the SG project saw BIM as a fully integrated process and workflow, and that there were many missed opportunities if it was not used to the full capacity among all participants. In this chapter, unraveling these multi-memberships was based on only individual stances of participants. The next chapter digs deeper into the interactions of these participants while using a shared BIM model, and how the different communities and memberships of these communities affect and are affected by the different types of interaction.

CHAPTER 5

TYPES OF INTERACTION AMONG DISCIPLINARY PARTICIPANTS

This chapter describes some of the prominent types of interaction that took place among the different disciplinary participants in the study. Three main types of interaction are described: 1) non-disciplinary interaction (architect-client interaction), 2) intradisciplinary interaction within the architectural team, and 3) interdisciplinary interaction with both in-house and external consultants. Specific events are discussed in each type of interaction to portray some of its main characteristics in detail. These events highlight issues such as interpretation of information and requirements, recognition of participants' needs, and the nature of coordination and information exchange in the shared space of team communication.

5.1 Non-disciplinary Interaction: Ambiguity and Interpretation

Three main types of interaction are discussed in this chapter: architect-client interaction, intradisciplinary interaction within the architectural team, and 3) interdisciplinary interaction across teams. Section 5.1.1 discusses some of the salient features identified in the first type of interaction: the architect – client interaction, related to the interpretation of client requirements by different team members.

5.1.1 Event 1: Architect-Client Interaction – Interpretation of Requirements

The communication between the client and the architectural team took several forms and resulted in different levels of interpretation of the client's needs. There were two clients for the SG project; (O1), head of the university comprising the project, and (O2) who succeeded (O1) during the DD phase of the project. The main difference between (O1) and (O2) was their approach to the character of the building. The architectural team had originally proposed a "modern" approach with metal cladding and curtain walls. (O1) preferred a more "traditional" approach that blends into the context of the university campus. As the team proceeded with this approach and was working towards the DD phase, (O2) succeeded (O1), and he chose to go back to the modern approach proposed originally. This presented a major challenge for the team. Both clients usually met with (P1) and (A2), and sometimes with representatives from the other consultants. There were two main levels of interpretation observed in this interaction: one-step interpretation, where the team attended the client meetings; and two-step interpretation, where (P1) and (A2) only attended and "translated" the client's needs to the rest of the team (figure 5.1).

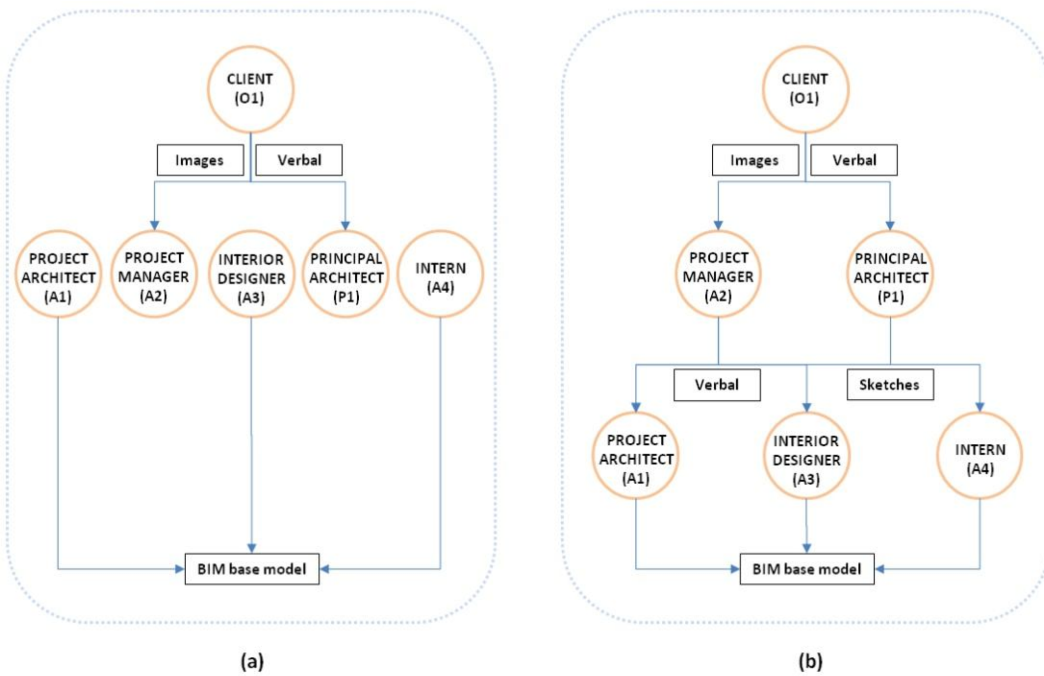

Figure 5.1. Levels of interpretation in the architect – client interaction: (a) One-step interpretation (client-team), (b) Two-step interpretation (client-principal architect, principal architect-team)

(P1) tried to make sure that either (A1) or (A4) or both of them would be present at those meetings so that the whole team was aware of the client's needs first hand with very little chance of having to "*filter*" the client's requirements and "*translate*" them in the subsequent phases of discussion within the team:

P1*: We take most of those people to all the meetings so they hear directly what the client is saying so there is very little filtering of the message and we try to agree as a team after the meetings.*

By doing so, (P1) wanted to avoid a two-step interpretation of the client's needs, where he would have to first interpret what the client said, and the team consequently would have to interpret what he translates to them. If either (A1) or (A4) attended those meetings, it was still an issue to translate those needs to the rest of the team. Even when most of the team attended the meetings, (P1) wanted to make sure that everybody "*heard*" the same message:

P1*: Well what did we hear? Because people hear different things – people have different interests so sometimes there is a selective hearing – well I didn't hear him say that because I didn't want to hear him say that – no he said that – that's what he meant.*

In an attempt to avoid this "*selective hearing*", (P1) meant to hold sessions with all members of the team including (A2) and (A3) to reconcile the different interpretations that everybody developed after meeting with the client. These sessions aimed at "*aligning*" the internal firm and team goals with the client's goals. For (P1), this was a necessary step before moving on to the next level, which involved discussing his design proposals with the team:

P1*: We have a robust discussion about that [what he client meant] and then try to align our internal firm goals for the project with the client goals and then make sure that there is a sort of buy in at the team level so that we don't have one person in the team interested in doing something that is not aligned with the whole mission of the project.*

(P1) focused mostly on introducing a wide spectrum of images of buildings as part of the mechanism of interpreting the client's needs and testing his "*taste*" along the traditional-modern spectrum of designs. This was usually a back and forth process, where both the client and the architectural team presented images representing a range of buildings, with the goal of arriving at a building character and a set of features that were the best fit for the client:

P1: *We had to have a discussion, ask him for buildings that he had seen, that he liked – and we went through three or four meetings in where we took images of various buildings that we had designed and other architects have designed, buildings that we liked – and put a whole range of buildings on the wall from more modern buildings to very classical buildings that might have pediments and moldings and very classical columns to buildings that combine elements that might have a pitched roof but a relatively modern approach to detailing windows and curtain walling and a more plainer treatment of brick without the ornamentation – we were trying to judge where does he fall on that scale from very traditional to somewhat modern.*

This represented a best guess at the client's needs through trying to understand the core of what his interest was, what building elements he said he liked, what he liked about them, why he liked them, and how all that translates into a modern building. (O1) was determined on a traditional building and explicitly mentioned some of the building elements that he was in favor of, such as pitched roofs, arches and brick. Although he seemed specific about his needs, they still seemed to be open to a lot of interpretation:

A4: *It was pretty much clear that the client wanted a pitched roof...so he wants the building to look in a certain way – he brought us an image and he was very specific about it – he said at one meeting this is what I want – so we said right we're trying to read through what he really meant – was it a historical or traditional – I mean what was it that he called traditional because he kept mentioning the word traditional and we didn't really know what he meant by traditional.*

Interpreting the word "*traditional*" itself was not an easy task, especially for (A4) who was assigned to design the overall character of the building and coordinate with (A1). Both (A1) and (A4) were going though the images and trying to "*read through*" the client's preferences. For (A4), this was a very concise and limiting "*language*" that was forced upon her:

A4: *He [client] got stuck into this idea that he wants a pitched roof – he wants colonnades – he wants if possible arches and brick – so it's just a certain language that he wanted us really to project.*

The process of selecting specific building elements and features was not the only issue that (A4) refused to take on easily, but also the timing of this process. (A4) believed it was too early at the schematic design phase to be discussing very specific motifs and features of the building:

A4: *They [client and architectural team] discussed architectural character and site location – to me this idea was odd in itself because when you as an architect start to bring into discussion architectural character you are going to get certain answers and this should not happen at this stage of design – so this is one of the things that not only I wasn't familiar with but I didn't think that was part of a process.*

This presented a challenge for her, as she was thinking about the building design in a holistic fashion at this stage of design and not into the details that would introduce a lot of fixation early on. For (A4), thinking about these details was limiting in terms of conceptualization and reflection. It was irrelevant to her because it did not give her the space to think about what the overall function and character of the building was at this stage:

A4: *I personally don't think that the discussion should have been taken that direction because I could foresee the end result – at that level you have to talk about what the building does – the larger picture – not if it's made out of brick or if it has a pitched roof – that is irrelevant – I don't think there is anything wrong with a pitched roof or brick in itself but there is something inherently wrong about saying that there is only one way to deal with it.*

The team took the decision to go forward with the path that the client chose, but this was a "*dangerous road*" for (A4) that they were stuck with, since it forces them to be framed within a preconceived notion of what the building "*should look like*". She therefore went into a separate incubation period to "*interpret the traditional*" and produce design alternatives through various freehand sketches and some physical modeling:

A4: *I started questioning the idea of traditional – I started interpreting the traditional – and I started to look at ways in which – I started talking about textures, about scale, about other ways, about mass and produced a bunch of drawings – it was me reading again complexity and architecture and just throwing thoughts.*

(A4) started to develop many schemes based on reading between the lines of the client's needs, and she began to produce many sketches inspired by Scarpa and Kahn's work. In every brainstorming session however with the rest of the team, her work was catalogued as too sophisticated. This was frustrating for (A4), as she could not proceed any further or did not know how to carry the design on to the subsequent level:

A4: *I was worried because I didn't know where to take it next and I didn't know where to take that – how to rely on that sketch because to me that said an image of tradition – to me that spoke about a collection of images – to me that spoke about imagery not necessarily tradition in itself – to me that image was a collage – and I didn't know if I was supposed to take the collage out of it or I should give my own interpretation of what tradition is.*

It was more frustrating for (P1), as (A4) was pulled out of the project to work on other projects in the firm. (A1) had to continue (A4)'s work and "*translate*" it once more from the vast amount of sketches, rendered images and physical model attempts into the BIM base model. As (A4) was completely detached from the project for more than two months, (A1) became the sole designer and drafter on the project. Not only did he have to do all the work, but also he had to make a lot of assumptions about (A4)'s drawings. With (O2)'s desire to go back to a "modern" approach to the building, the strategy of the team shifted from the "interpretation" mode to a more practical approach that involved primarily façade and exterior material studies. With cost being a major issue in the middle of the design development stage, the key component in these studies was working with alternatives for the building façade that respond to the available project budget:

A4: *We wanted to tell them this is how much brick you can afford – this is how much stucco you can afford and this is much metal you can afford – because they all agreed that these are the materials for exterior skin that they wanted to have there.*

This was a process that both (A1) and (A4) were involved in but with different methods and approaches. For (A1), this was a clear cut process that went well with his modeling approach. He could now make use of the parametric relationships of building elements that he had set up earlier in schematic design to study multiple façade alternatives and exterior material and texture options, and whether they fit within budget or not based on the generated schedules. One of the key procedures in these alternatives was adjusting the relative percentages of brick, glass, stucco and metal cladding:

A4: *We tried to come up with an exterior skin that would meet that budget and make us happy – and it was a little bit of a struggle because we don't have money and after the estimate we realized that we can afford that much glass percentage wise and that much stucco – that much void and that much solid which translated into that much glass – curtain wall and punched windows or whatever else skylight whatever we have – and that much brick and stucco so we had to operate within those limits.*

Although working with these percentages of exterior material distribution was one of the goals of (A4) as well, the process was more than just a systematic method for "*composing the façade*" but more of a study of building "*tectonics*" and an interpretation of the integration between the façade and the rest of the building components that served a specific philosophical concept in her mind:

A4: *I'm focusing on tectonics and how you can read this building in terms of its tectonics and understand the method behind this design so for example you look at one part of the façade and you understand that there was scoring going on there and then the plane folded and then it did something else and it was at some point a part of a bigger plain sheet.*

(A4) could still only use freehand sketches and rendered 2D images to express this process because it required a lot of attempts and reflection. Revit was more of an obstacle for her in terms of effectively and quickly producing such a wide variety of façade alternatives, and so (A1) relied mainly on (A4) to work on building elevations at some point rather than doubling the amount of work. As (A4)'s work was mostly in the form of 2D rendered sketches, they had to be drawn later by (A1) in the base model, but the priority was to get quick façade options for the client to choose from:

A1: *Essentially everything is in Revit except for elevations because we haven't – it takes a long time to do elevations to get that looking good – it's a lot easier to do it by hand especially in a short time frame…it was just freehand and photoshop.*

This compromise and alternation between modeling and sketching took place on a frequent basis for both "traditional" and "modern" approaches. According to (A1), the careful setup that he did in the base model beforehand allowed him to perform more studies in the "modern" approach because the variables were much more clear (percentage of glass, stucco, brick, etc.), less open to interpretation and easier to control and adjust in the model. For (A4), sketching was dominant in both approaches because she was more driven by the design parti in both cases, and she could express it in a flexible and seamless manner through freehand sketches and rendered images. In both cases, sketching and quick and dirty rendering were more efficient in “translating” and responding to the client’s needs. The burden that emerged however was the redundancy in having to model those sketchy alternatives yet again to represent the final design alternative in the base model.

5.2 Intradisciplinary Interaction: Conceptualization

Figure 5.2 illustrates the main tools and representations employed and exchanged among the architectural team members in the SG project.

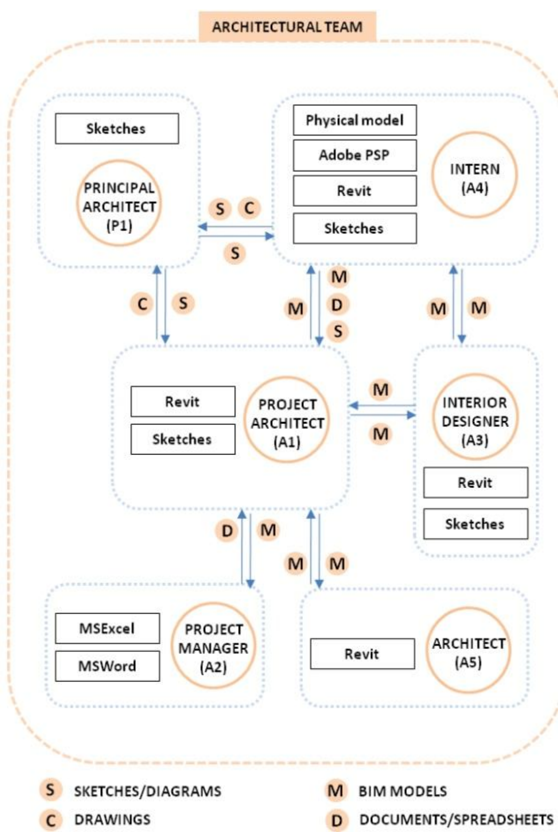

Figure 5.2. Tools and representations employed in the interactions within the architectural team in the SG project

This section discusses some of the salient features identified in the second type of interaction: intradisciplinary interaction within the architectural team. Section 5.2.1 involves the interaction between the principal architect and the team members, and some of the conceptualization and interpretation mechanisms that take place in design thinking sessions. Section 5.2.2 involves team-team interaction, where top-down and bottom-up design approaches affect the way architects within the team perceive the BIM model. Section 5.2.3 discusses issues related to the scope and level of detail of modeling that were brought up in architectural design meetings. Section 5.2.4 involves opportunities for design reflection in meeting sessions by means of navigating collectively through the BIM base model as a shared space of thinking.

5.2.1 Event 2: Design Thinking Sessions – Mixed Messages

(A1) and (A4) were assigned separate parts of the project to work on by (P1) in schematic design and early design development phases. (A1) was assigned to work on the laboratory spaces and other functional spaces, while (A4) was assigned to work on the main atrium of the building. (P1) would usually draw conceptual sketches, have collective team meetings in the hallway, and ask the team to pin up what they have been working on and discuss it:

P1: *Somebody may be studying the lobby space and how we get a stair from the ground floor to the upper floor or (A3) may be working on three or four ways to arrange the faculty offices and the conference rooms – (A1) may be working on the structural system of the building – and so all of that has to come together, so we usually try to put that up on the wall and talk about it and get everybody aligned on the same message and make decisions – and then everybody is aware of what we are doing – if there is other investigations to be done we'll talk about what needs to be done and then set a time to get back together to look at the results of those.*

(P1) preferred physical meetings and discussions over print outs of the model and sketches in order to reconcile the individual tasks carried out by the architectural team members. Very rarely did the team meet over the actual BIM base model, navigate through the 3D space or resolve conflicts that may arise from these individual tasks, although some expressed an interest in using that as a strong tool for visualizing the design:

A4: *That's one thing that we didn't use as a team and we didn't have those discussions design wise as a team…I realized that we could have used the 3D model and talk about issues right there as we're manipulating it…well it was a missed opportunity.*

In these physical meetings, there was another level of interpretation that came into play. It was different than the client-team relationship which was many times open to ambiguity. (P1) "*spoke the same language*" as the team, where he mostly translated his understanding of the client's needs into freehand sketches and diagrams. This decreased the level of ambiguity but was still open to a lot of interpretation. In spite of (P1)'s continuous efforts to align different interpretations, there was occasional miscommunication that would lead to team members making different assumptions with respect to what they actually heard:

A4: *It was probably a matter of miscommunication too because (P1) and I sometimes wouldn't even finish the sentence and we would say ok got it – and then of course (A1) was kind of lost in the game – what is going on? So he would interpret things and they wouldn't turn out to where (P1) and I thought they would but we probably didn't do a good job in communicating.*

As discussion and verbal communication mostly dominated the team meetings, both (A1) and (A4) often got different or mixed messages from (P1), and upon revisiting the subject of matter (P1) would have to reiterate his ideas yet again to the team or some members of the team:

A4: *Sometimes there is miscommunication between (P1) and I – I would say ok got it and then half an hour later (P1) would say no it's not that and then I would say ok let's rethink – it's just how it is in a team.*

(P1)'s sketches were also another cause of ambiguity among the team members, as they were open to their own "*reading*" of design elements or concepts. They were more "*powerful*" though in conveying design ideas according to (A4) than Revit plans, perspectives or renderings:

A4: *You can't pretend that someone else would be able to translate a sketch – and a sketch is always more powerful than a stupid drawing – I mean seriously this Revit it might be a wonderful tool but it looks terrible when you do it – and I hope there are ways to make it look good – either (A1) doesn't know or doesn't care or there is no way to do it but they look terrible.*

In return, the conglomeration of representations (sketches, diagrams, rendered images, model plans and perspectives) that (A1), (A3) and (A4) would usually present to (P1) in their team meetings resulted in rich feedback. Discussing design concepts and alternatives solely over print outs pertaining to these different representations and media, in spite of the richness they did offer, led to developing a wide range of assumptions by each team member. Each representation had its advantages and disadvantages:

A4: *I was always in advantage by drawing by hand and I didn't want that – it's not fair because we were discussing design and we were showing different media – (A1) with the horrible Revit thing and I drew well – what can I do?*

Being "*in advantage by drawing by hand*" was actually a significant factor that made (P1) often think that it was better if (A4) worked with him on the *designing* component of the project and (A1) on the production component. She still thought that this introduced a heavy burden on (A1) and not fair in terms of task assignment, as it was not "*his fault*" that she was "*an idiot with Revit*", and so she started to jump into Revit and use it in the middle of design development. (P1) also encouraged her to do so because he realized that there was an everlasting disconnect between (A1) and (A4) because they were using two completely separate media that do not "*communicate*" together. (A4) believed that Revit was like any other software, and that she could "translate" whatever she sketched onto the base model:

A4: *They kept pushing me to get into the Revit model and take over this thing – if I draw something I should be able to – if I draw something in sketch or if I think about something I should be able to draw in the model.*

The steep learning curve however and her continuous struggle and slow pace with using the tool did not allow her to be of much help in modeling, and (A1) had to "*take over*" most of the modeling work again:

A4: *I said I'm going to take over but I don't want to mess up with what you've done so he [A1] created 'design options' so I worked on 'design options' – that wasn't bad for me because I thought in the middle of what I'm doing I'm not going to mess up with the main model – however we had a deadline so he took over and we said this is not working and he started drawing again.*

5.2.2 Event 3: Top-down vs. Bottom-up Design – Different Perceptions of the BIM Model

In the schematic design phase of the SG project, (A1), (A3) and (A4) worked using different representations, including physical models, freehand sketches, and computer renderings, in addition to different portions of the BIM base model. They used Revit Architecture to model the main masses and spaces of the building. They had different perceptions though of the base model and what it "meant" for them. This section highlights some of the striking differences in perceiving the base model between (A1) and (A4). Work experience and background played an important role in how (A1) and (A4) identified with the BIM model. Both were assigned specific tasks by (P1), but their approaches to the process appeared to come out of two different schools of thought and tended to be at two ends of the bottom-up top-down spectrum. (A1) generally adopted a bottom-up approach, starting with a pragmatic "*stacking*" of masses and spaces as building blocks that satisfy the design program to "*get the job done*" (figure 5.3).

(A4) however followed a top-down approach with the design always necessarily beginning with a parti. As (A1) had previous work experience, he appeared to be moving ahead at a faster pace with the design, having a "*direction*" and being "*more clear*" with procedures and with task accomplishment than (A4):

A4: *For (A1) maybe to him things seem more clear but there was an odd thing that happened at some point – when I came up with an idea, (A1) came up with something else and then (P1) made us switch and that just confused me…(A1) seemed to have a direction while I was completely lost because to me that was completely illogical.*

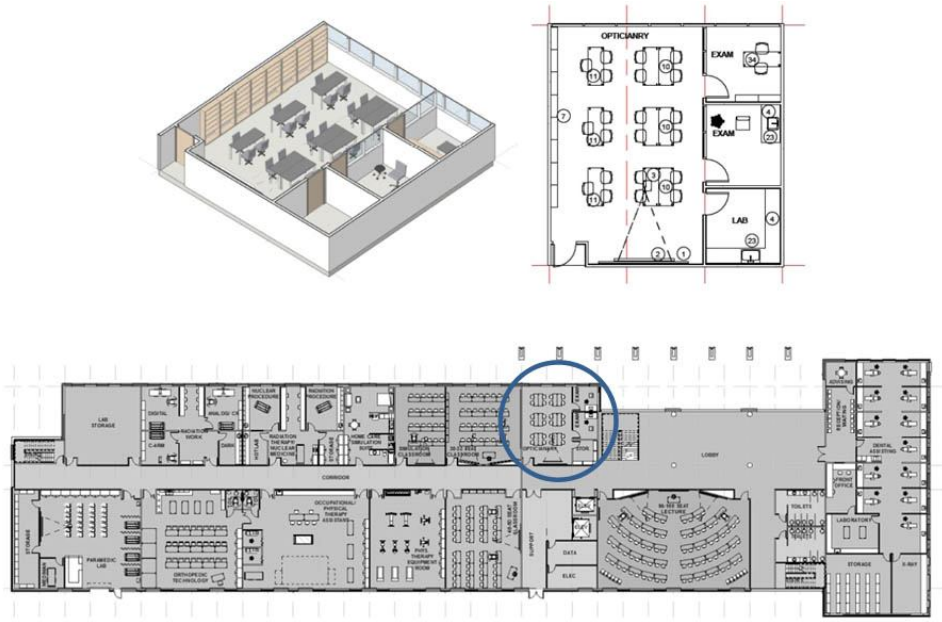

Figure 5.3. (A1)'s bottom-up approach: a "stacking" of masses and spaces with finite description

This was "*illogical*" for (A4) as she needed more time to conceptualize and walk through the different design alternatives and ideas with a persistent desire for prolonged discussions about how to proceed from a philosophical standpoint. This tendency to hold "*philosophical discussions*" and spend endless hours on developing an overarching concept for the building was partly affected by her teaching experience, but introduced a conflict with the project imminent deadlines and constant pressure by the architectural team to wrap up specific assigned tasks:

A4*: We didn't have too many critiques but what usually happens I'm starting to get into philosophical discussions and I'm making people tired and (P1) says ok so you're going to do this and you're going to do that – but I don't know I can't really work without a philosophical discussion.*

Figure 5.4 shows some of (A4)'s early design sketches. Although (A4) was "*making people tired*" through her continuous discussions which appeared to be more of an obstacle in the way of proceeding with the design, (P1) relied on her more in *designing* rather than (A1). He was more confident in her ability to perceive the larger picture of his design ideas and not just adopt a systematic bottom-up approach. However, as (A1) was generally in charge of the base model, he would be the one to *translate* all the ideas that were discussed in design meetings and brainstorming sessions and (A4)'s sketches into the Revit model.

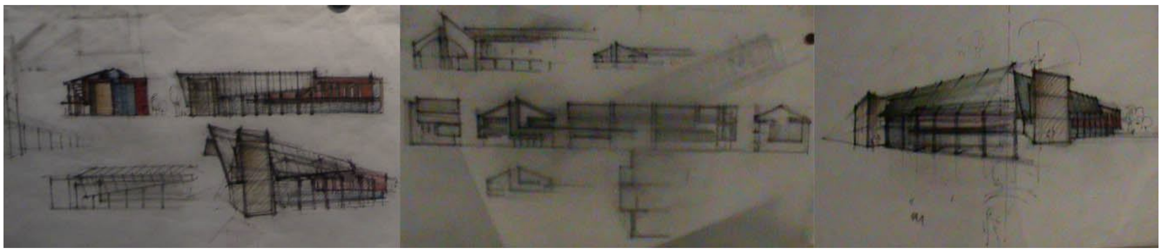

Figure 5.4. (A4)'s top-down approach: design as parti with "philosophical concept"

There were therefore two disjoint processes going on; discussions, design decisions and rough sketches by (P1) and (A4), and the modeling effort, which was carried out mostly by (A1). As he was proficient with the tool and its functionalities, he used it to externalize his design approach, where the model at schematic design represented a "*stacking diagram*" but at the same time at a certain level of detail that connotes a functional plan:

A4*: He [A1] was the only one familiar enough with the software to know and to understand…it was a stacking diagram…for us it started to be a plan.*

This is where the base model representation became perplexing, especially when different levels of detail and perception came into play. While (A4) expected the model to represent a stacking or bubble diagram that was still at a preliminary level, (P1) would go into aspects that were too detailed for this kind of representation:

A4*: (P1) told me that instead of going into so many directions I should just stick within 3 feet of the façade – and that's when I got very confused because of the fact that this was a stacking diagram and not a plan.*

This was not only due to the fact that the tool allowed for this level of detail to be represented at this stage, but also how (A1) used this feature to *see in* the model different layers of representation. For him, it was a stacking diagram but that same diagram would potentially *transform* into a full virtual representation of the building, and also *mean* other things for him, such as cost and scheduling. (A4) however thought that it was too early to *see* the model *as* a plan because it still needed much more refinement to *become* a plan since it was literally a horizontal and vertical stacking of masses. That is why "*sticking within 3 feet of the façade*" for her was totally out of context and it represented another very different language. It was a question of: how can she go to that level of detail and precision with a bubble diagram that involves a preliminary conceptual stage?

As the conflict of perceiving the base model between (A1) and (A4) escalated, (A2) had to step in to resolve the issue and make important decisions in order to proceed with the design. As project manager, (A2) was responsible for overall coordination of tasks but was usually informed about details of the project indirectly through (A1). She trusted him with this project because of both his work experience and proficiency with using Revit:

A2: *(A1) has a lot of experience so I feel like I can kind of rely on him to kind of tell me what do I need to be aware of as knowing what I need to be doing – what is it that I need to be told or be shown or be made to understand so that I don't miss something along the way – and I think that's why the team is maybe more important with a BIM project than it is with other projects because everything is so integrated.*

(A2)'s knowledge however of BIM tools was limited and she completely relied on (A1). It was her first experience with Revit in an architectural project:

A2: *It's really going to be a learning process for me to go through a project from beginning to end in Revit – I have not done it before and I have taken one class to understand Revit and to understand BIM more so from a project manager standpoint and specifically about how to get in a model and not blow it up.*

At the same time, because of this full dependence on (A1), (A2) was not very familiar with the details of the design aspect of the project. She had to intervene however to propose a resolution for the conflict concerning interpreting what the model means for (A1) and (A4):

A4: *All she [A2] could see was this stuff (the Revit plan) and just a few of my sketches – she wasn't familiar with our entire process…with the model…I mean she saw them but she had no idea what this was.*

Being "*outside of the model thing*", (A2) was slightly disconnected from the process of modeling and the associated inconsistencies that took place between (A1) and (A4). She would occasionally follow the progress of the team through pin ups of print outs of the model and sketches, brainstorming sessions and verbal discussion, but was not familiar with the entire details. She was aware however of the limitations of the tool with respect conceptualization and having to make a lot of decisions beforehand:

A2: *That's going to be a little bit of an adjustment for me but I think it'll just be more of sessions sitting down with the team and doing just some quick pin ups and seeing where are we with the model and let's look at it and bringing it up on the screen and trying to understand the level of detail – because I think it forces you to make a lot of decisions – and so to me I'm thinking what kind of decisions are there being made early on in the process that maybe I'm not necessarily aware of because I'm kind of outside of that whole model thing.*

By simply "*asking questions*" in the brainstorming sessions, (A2) would point out significant issues as an *outsider*. She realized that (A1) and (A4) were stuck in their perception of the BIM base model and what it meant for each of them:

A4: *She [A2] started asking very very valid questions…and I started pulling drawings and I said we already studied that and we already studied that and we did that and we did that – and just by asking questions she kept saying listen you guys are stuck into this…and let's just think about this as a bubble diagram.*

She also realized that the appropriate way to *look at* the model in this stage was to perceive it as a bubble diagram because it was too early to think of it as a functional plan. Using Revit from day 1, according to (A4), resulted in a fixation that affected the evolution of the design from beginning to end. To her, it was hard to depart from the functional plan view which was already similar to the initial stacking diagram because of this fixation. It was equally hard to develop alternative schemes because of the mixed perceptions and views from both (A1) and (A4):

A4: *Everybody was complaining while we were having these critiques – they were complaining about how detailed the layout is and it wasn't even a plan yet and how it looked like a plan – it is very possible that our present plan is so close to the functional layout we had before because they were so similar – because we couldn't get away from the fact that they were so similar – the functional plan looked like a plan – it is very possible.*

The fact that the layout "*looked like a plan*" but "*wasn't even a plan yet*" added to this sense of fixation and the unusual level of detail that had to be embedded in the model at an early stage of design. While (A1)'s model forced most of the team to "*fall into the trap*" of the mixed messages of what the layout represented, (A4) saw that her sketches were more clear and expressive. While (A1)'s iterations of the model were mostly not so *different*, the evolution and expression of the design, and the transition from the functional plan to the plan itself were more *visible* in her sketches.

This presented a limitation for her in terms of the capacity to conceptualize and reflect solely in the model. She suggested that this "*language*" that (A1) and other expert modelers employ in their process demonstrates how a BIM tool "operates" in the minds of the team when they are not competent enough with the tool:

A4: *And that will say something about how Revit operates in our minds now because we're not used to it – once we get used to it – because (A1) was saying oh to me this is still not a plan I see it as a functional – but we all thought it was a plan – he is used to it – so for people who are used to this kind of language the functional stuff is really not a plan – for us it was.*

The tool therefore was more limiting for (A4) in early design phases and was more of an obstacle, as it did not allow for her top-down approach to be articulated. She thought that the base model was more useful and efficient to use for later design development stages when the design was more defined. (A1) however could seamlessly express his bottom-up approach using the functionalities of the tool and could carry it over easily to subsequent phases. The model was therefore more efficient for him in the schematic design phase. This discrepancy in perception of the BIM model and design approach affected how (A4) pictured (A1)'s contribution in terms of *designing* the building. She believed that he seemed to adopt an "engineering approach", focusing on just getting the job done and stacking some spaces beside each other in a way that works practically but does not necessarily guarantee "good design".

5.2.3 Event 4: Model Coordination within Team – Scope of Modeling

In design meetings within the architectural team, (A1), (A3) and (A4) often had discussions about model coordination and how to use the BIM base model efficiently. Most of the discussions were concerned with the scope and level of detail of the model. The typical conversation was oriented to questions of whether to represent certain elements, how to represent them and to what level of detail they should be represented for coordination and effective workflow purposes. The following dialogue involves discussions within the team during early design development about representing equipment and furniture elements in the model:

A1: *(A3) you will notice one thing that you will see here – we will have to go through and maybe spend a little time to coordinate it just the way you want it – you will notice all the furniture and equipment is dashed out.*
A3: *Because we want to turn that off in the floor plans right?*
A1: *I think if we leave it dashed it reads pretty well.*
A3: *Yeah but once you get all your dimensions and notes and everything on the plans it will be too…*
A1: *I think for DDs it's ok but once we get into – because I think we will be doing major dimensions here – once we get into really fine tuning here and dimension line dimension line dimension line.*
A3: *I just honestly (A1) I don't think we have a need to do that because we usually don't see it very much on the floor plans.*
A1: *Yeah and we can even half tone it.*
A3: *We usually have like a furniture plan which says furniture not in contract.*
A1: *Essentially I think we should try to keep it on one plan if we can – and if it's not too busy then we can isolate it but we can take these and do them half tone – I've got different – I've got furniture systems and specialty equipment so I think what we'll have is we'll have – we can do schedules based on furniture – obviously there is equipment that is actual equipment like dental chairs – we can have the equipment and furniture schedule or we can have a tag that says furniture not in contract.*
A3: *See that's going to be a bit more complicated.*
A1: *I'll leave that...*

A3*: With other projects – all the other projects I worked on just have it on a furniture plan because the floor plan gets way too much information – I mean maybe you will have to split it up into notes and dimensions because it's too much information.*
A1*: If you open up a family (Revit family) go to categories and parameters it says furniture it's supposed to be specialty equipment – close it and save it back and then schedule on the right.*
A3*: OK.*

As an interior designer, (A3) was accustomed to a certain method of work with furniture and equipment that implies having separate furniture plan views rather than displaying them in the base plan. By "*we usually have like a furniture plan…*" and "*all the other projects I worked on just have a furniture plan…*", (A3) refers to associations with not only the *community* of other participants she had worked previously with on other projects, but also the *community* of interior designers at large she belongs to, with its own standards, methods and procedures. (A1) was more focused as an expert modeler on incorporating maximum elements in the base model to facilitate coordination and visualization among team members. According to his viewpoint, why not model and display most building elements, including furniture and equipment, if the tool allowed that and it would potentially enhance visualizing the spatial qualities of the building for all participants?

A4*: So for this phase are we going to show the dental chairs – I'm just curious.*
A3*: The way I've seen it in the past is you have a furniture and equipment plan at the very end of the set and all it is is a reference sheet – and maybe then it will say this is a dental chair not in contract and it will say all this is not in contract for reference only – I don't know how we want to do that.*
A1*: I mean I think we need to show it.*
A4*: To show it in plan so that they can understand it?*
A1*: Equipment and furniture can have – we can just have a note – we're going to have general notes on the floor plan anyway – we can just have notes and put something in there – but I mean you just put something that says furniture provided by owner not part of contract.*
A4*: We have to show it in plan though right?*
A1*: I mean I think we need to show it.*
A4*: We do or we don't?*
A1*: You know I was looking at different sets that have already shown furniture but isn't in contract just for spatial –so you can see it spatially.*
A4*: Yeah.*

A3*: Only on one plan or the whole set though?*
A1*: We can figure that out – there is a lot of information on these sheets – we'll just have to see if – there is not a ton of information in here because it's just a flat floor but I mean we will get additional walls and all that other stuff as it goes along – we'll just have to see how the set develops – I don't want to add sheets right now.*

The persistent "*I think we need to show it*" reflected (A1)'s preference to include more detailed modeling for better spatial visualization, and at the same time to be efficient in terms of number of sheets, where more information is more integrated and less scattered across project sheets.

A4*: So for example for the 100 seats are we going to show the seats or not? Because those ones are included right?*
A3*: Well (A1) is proposing that we do and I'm proposing we do too – it's just where we show it – I mean I don't mind if we show it like that but I think we need to show it on a clean furniture plan so that that is all that you see as furniture and equipment – because it gets really hard to read both things on one plan – so if you want to show them on the floor plan then that's fine.*
A1*: I mean we can do that – I mean either way is fine – I'm just always trying to keep the sheets to a minimum – it's just more sheets to manage.*
A3*: It is.*
A1*: I mean I can make these half tone so you can barely see them but you realize they are there – we'll look into it.*
A3*: It really needs its own sheet because if they hire us to do furniture and equipment then that's the sheets that they will use.*
A4*: I was about to ask – I mean they have to hire somebody else or us?*
A3*: Well (A1) acts like he's going to do it himself – he's going to take that sheet and hand it to you – the furniture dealer you know.*
A4*: Or he's going to build the dental chairs himself.*

For (A3), there was no disagreement about furniture and equipment being modeled in the first place. The controversy was over where they are represented. Although spatial visualization was one of the benefits the tool offered, (A3) did not feel the need to represent those model elements to that maximum level of detail, especially when somebody else would be hired to do the furniture work. A furniture plan was then enough for the purpose of this project in her viewpoint.

A1*: Do we handle putting our little outlets in there?*
A3*: That's what I was going to ask – no typically I would send them the furniture plan and place things according to that and then sort of relate it to their view – we may have*

like a 30 minute meeting just to go over electrical strategy especially for like the labs and stuff – see I was just curious about how that all is going to work – so if they need things from us or we're waiting on things from them – are we going separate ways here?
A1*: I don't think that will be in DDs but – that coordination stuff.*
A3*: What do they have?*
A1*: Hopefully they have something.*
A3*: Specs maybe.*
A1*: So I think we'll put some specialty stuff in ours like if we require – like wherever the compressed air is – then we show that temporarily so that they know – we can just put a detail note on there.*
A3*: What are we going to do about that – that dental – you said we need a compressor – do you have it far away so you can switch it on?*
A1*: I mean it's going to have to be in a backroom.*
A3*: Lord – I haven't done RCPs (reflected ceiling plans) in a long time.*
A1*: It's easy – now things like soffit walls – I mean if it's – just draw a gyp ceiling because that's the only place you see it – now if we had a section cut through it or something we can kind of fudge it later.*
A3*: Yeah we'll probably fudge it later.*

The "*fudge it later*" process summarizes the approach that (A1) and the rest of the team reached consensus on and adopted later on with regards to modeling. Although (A1) seemed to promote going to sophisticated levels of detail to represent building model elements, he only implied that as a tool to help the team in their design process; for better conceptualization and visualization. For coordination however, whether within the team or for later coordination with the consultants, his approach was to reduce 3D modeling as much as possible. He preferred *partial* modeling in most cases where "*that's the only place you see it*" and "*fudging*" the process only when needed and if that part of the model would appear to others sharing the model in specific views.

A3*: Well it depends – are we going to do any quantity take off or anything from this model? Is it going to be a super Revit model or the just it looks right model?*
A1*: Well I have not heard the demand for it – I think if somebody asks for it.*
A3*: You know that we have to turn it over to them right? To (the funding agency) and to (the client)?*
A1*: I'll have to ask.*
A3*: Nobody really know what they really want or what to do with it once they get it but isn't that one of the requirements?*
A4*: What – the Revit model?*
A3*: Yeah to give them a model – I don't know that they know what to do with it – that's the last I heard.*
A4*: Well they have their CAD program – I'm sure they will know what to do with it.*

The bottom line was in fact the method of delivery of the project and whether accurate information was to be extracted from the base model or not. In this groundwork phase within the architectural team of preparing the model for exchange with consultants, a "*super Revit model*" implied potentially more detailed modeling with greatest attention to accuracy and validity of the information embedded in the model. A "*model that looks right*" represented a pragmatic approach, especially if no regulatory body would "check" the model for consistency and correctness. At the same time, it implied just a reference model for coordination which required more communication channels with the consultants to provide the necessary information for their calculations and analysis process.

5.2.4 Event 5: Navigating through the Model – Opportunities for Reflection

Using the BIM base model for visualization and navigation was one of the effective but not so often exercised activities within the architectural team. Only a few design meetings used the model as a means to reflect and develop the design of the SG building. In most of the meetings, the team would meet in the hall, pin up print outs of the drawings and sketches. This was true for most of the building spaces. For more complex spatial configurations such as the triple height main lobby, the team would open the Revit model for a detailed study of the 3D configuration of the space. In the following conversation, (A1), (A3) and (A4) discuss the design of a light monitor in the main lobby space in the middle of design development, using the Revit model projected on a screen in one of the meeting rooms in the firm.

A1: *I think having this – just a light monitor above here (pointing to lobby space) would be really…*
A4: *It's going to reduce our cost.*
A3: *What – around here – that line?(directs a pointer to the projected image of the model on the screen)*
A4: *It's going to be a tiny little thing though.*
A1: *Actually that doesn't look right (brings up a plan view of another level) – not that right – because the upper classrooms are here.*

A4*: But maybe it can be extended to there (A3 directs the pointer to where she assumes A4 indicates).*
A3*: Or maybe put a little wall here or extend that out.*
A4*: It should be extended – if we are making it shorter it should be up to the point where you showed (A3).*
A3*: Or something to bring that…*
A4*: To bring a little bit into the third floor – on top of the third floor.*

In this segment of the meeting, (A1) was in charge of navigating through the model on the computer. (A3) was standing beside the projection screen, using a pointer to guide both (A1) and (A4) to parts in the model they started to discuss. (A1) was first switching between plan views to figure out where a suitable location of the light monitor could be. (A3) and (A4) began to reflect on the views and discuss possible adjustments to that location. When they all needed more clarity in terms of 3D spatial configuration, (A1) started moving between different views, including plan, section and 3D interior perspectives.

A1*: Here? (brings up plan view of third floor)*
A4*: The other one – yeah there – up to there (A1 moves mouse to point to where he assumes A4 indicates)*
A1*: You want to lock that beam through there? (begins to move walls around)*
A4*: No no no – what I'm saying is – I think we are talking about two different things (moves to projection screen to explain) – I was just saying…*
A3*: If that ends there…*
A4*: The light monitor should end here if anything should end if we want to make it shorter not here – you know what I mean?*
A1*: OK – but the floors above come to here.*
A4*: It's alright because they are going to overlap in section a little bit you know you're going to have…*
A3*: I see what (A1) is saying though.*
A1*: (brings up a zoomed in view of atrium) oh yeah – probably you want to stop it here because this…*
A4*: But it's alright if they overlap a little bit – would that be a problem?*
A3*: But it's not – that's not going to work though on the first floor – it can't extend over.*
A1*: (brings up a section view and zooms in) if you extend it over – oh – where are we? We're saying it's right there – if we extend it to here (pointing with mouse to the location A4 suggested) then this glass has to come up and underneath and…*
A4*: Oh.*
A1*: Here it would be a clean piece (pointing with mouse to the location in section that he preferred).*

A3*: Well maybe we can do something with the floor finish or something to bring that line – it kind of looks like it's in the middle of nowhere you know.*
A4*: Yeah.*
A3*: (A1 brings up an interior 3D view) In the 3D view it doesn't read the same – looks better.*
A1*: Oh – the light monitor isn't even in the right place (switching to another view) so say the light monitor goes right down through here.*
A4*: Yeah.*
A1*: So it continues past…*
A4*: Yeah that's what I wanted – to continue past that.*
A1*: It would stop right here.*
A4*: I think it's odd if it stopped here but anyway (A1 switches to a rendered view of the same 3D view) – it's kind of nice to continue.*
A1*: I kind of like the idea of – going through there that just separates it from this.*
A4*: Right.*
A1*: And that makes this like a glass box here (pointing with mouse to the glass box area on the 3D view) because that has to be separated – and then this piece is open and the light comes from the stair – the main stair all the way across.*

As (A1) started switching between plans, sections, interior perspectives and rendered perspectives, zooming in and out and panning, and moving walls to test possible locations and resulting space quality, the team engaged in more detail in the discussion. Comments and suggestions started to build up that expressed a more detailed and focused understanding of the location of the light monitor, the quality of the space, and an accurate description of different spatial relationships like "*yeah there – up to there*", "*lock that beam through there*", "*the floors above come to here*", "*that ends here*", "*extend it here*", "*has to come up and underneath*", "*continue past that*", "*looks like it's in the middle of nowhere*", "*going through there just separates it from this*", and "*then the piece is open and the light comes from the…main stair all the way across*". With the continuous process of reflection and exchange of ideas, the team members started to *read* more into the model. (A3) took the conversation to another level, when she asked (A1) to apply interior views at specific camera angles.

A3*: Can you shoot one like here? That way? (standing up and pointing at a desired camera location she wants to visualize a different part of the 3D view) so we can see into that little seating and see that big wall on the first floor? I wonder if we can get a camera – if we can get it to rotate around to where you want…*

A1: *It's a little tricky (expands 3D view window to the right to expand camera scope and applies a rendered view and pans).*
A3: *Can you walk up the hall? (A4 laughs) yeah if you walk down a few columns then move left – can you do that? (A3 and A4 laugh) – well that's what – you know what I mean – you can walk can't you? Does it still do the…?*
A1: *(after getting to a suitable view) I think that helps – you get an idea of the massing and here is the best view that comes under.*
A4: These are so...
A3: *That's the little seating area and the wall.*
A4: *That's where I start to love Revit – you get all these interior stuff just like that.*
A1: *You can't really see the light monitor though.*
A4: *It's awesome.*
A3: *So that's where you can look up and see through stories up.*
A4: *Yeah and I like it to continue – we'll see.*
A1: *Oh we're under the table (A3 and A4 laugh).*
A3: *Oh I didn't know what that was - there we go – yeah that will look great by those columns – don't you think?*
A4: *I think so.*
A3: *I like that – very dramatic.*

This allowed the team to "*see into*" the seating area and one of the big and plain walls in the lobby that needed an element of detail to it. This developed to (A4) suggesting "*walking up the hall*", "*walking down a few columns*", and "*moving left*" in the lobby space. The conversation moved to a different level of immersion in the space, where the team were almost standing in front of the elements they wanted to study and started to propose ideas and different scenarios.

A3: *I think this would be a great space in here (A1 showing another interior view).*
A1: *Yeah this is kind of one wall.*
A3: *This will be our photography space right here – that's what they'll take a picture of –which I'm sure they will actually – we're trying to really get into more technical college projects.*
A1: *It's this wall right here – be careful it's…*
A3: *Yeah it's a plain wall ha?*
A1: *Yeah but it could be done nicely – we could put a super graphic – you know what would be cool – if we could do fritting on the glass as a super graphic and then it comes in and translates across that wall – that could be a cool idea.*
A3: *We could have some reveals of the gyp board or something…*
A1: *Yeah do some reveals throughout – or we can do reveals and replica and then just do like a subtle like – it's white paint and then it's off white so it's real subtle.*
A4: *That wall there you should be able to see from all floors – the entire atrium.*
A3: *You're really going to see it.*

A4: *You are going to see it from everywhere – that needs to be good.*
A1: *We can do a…*
A4: *Fur.*
A3: *Painting.*
A1: *(moves to plan view) what if we take this wall but instead of solid – I think we talked about that before – but do slivers of like channel glass – not channel glass but like frames…*
A3: *Slots?*
A1: *Yeah slots through there – and then maybe we do – continue that treatment there or something all the way through – that would be something interesting.*
A3: *Or at least that flavor coming across.*
A1: *I think it's just there as a placeholder – it's all glass right now.*
A3: *Yeah I think that would be great because you can kind of walk and kind of see little shadow pieces of…*
A1: *Yeah you can do frosted glass – half and half.*
A3: *And if we don't have any money – which we don't – I've been using a lot of the 3M film – and it actually turned out really nice.*
A1: *Yeah – I mean that has to be a smoke barrier.*
A3: *If you have glass and then you put the film on it – I don't know which side – probably the lobby side.*

A new *space* of thinking began to evolve among the team members. The team realized that the wall is actually "*plain*", seen "*from all floors – the entire atrium*", "*you are going to see it from everywhere*", and that it "*needs to be good*" and needs a lot of "*treatment*"; something that may have not come up without navigating through the model at this stage in the project. Different opportunities and suggestions for wall treatment then began to emerge, like paint, glass fritting as a super graphic, gyp board reveals, slivers of channel glass, half and half frosted glass, and others. Other considerations built up as well, such as realizing the significance of the triple height lobby space and wall as a potential "*photography space*", marketing potential for getting in other technical college projects for the firm, and budget considerations such as using reasonable materials at low cost. This detailed navigation of the model, with its different stages, enabled the team to read more into the design and reflect on several issues. This was not employed frequently however in other meeting sessions.

5.3 Interdisciplinary Interaction: Shared Space of Communication and Mutual Understanding

This section discusses some of the salient features identified in the third type of interaction: interdisciplinary interaction, both with in-house consultants and external consultants or AEC consultants. Sections 5.3.1 through 5.3.3 introduce three key events related to the interaction of members of the architectural team with the in-house cost estimator (C1). These events identify issues related to the recognition of needs of disciplinary participants. Figure 5.5 illustrates the main tools and representations employed and exchanged between the architectural team and the cost estimator (C1) in the SG project.

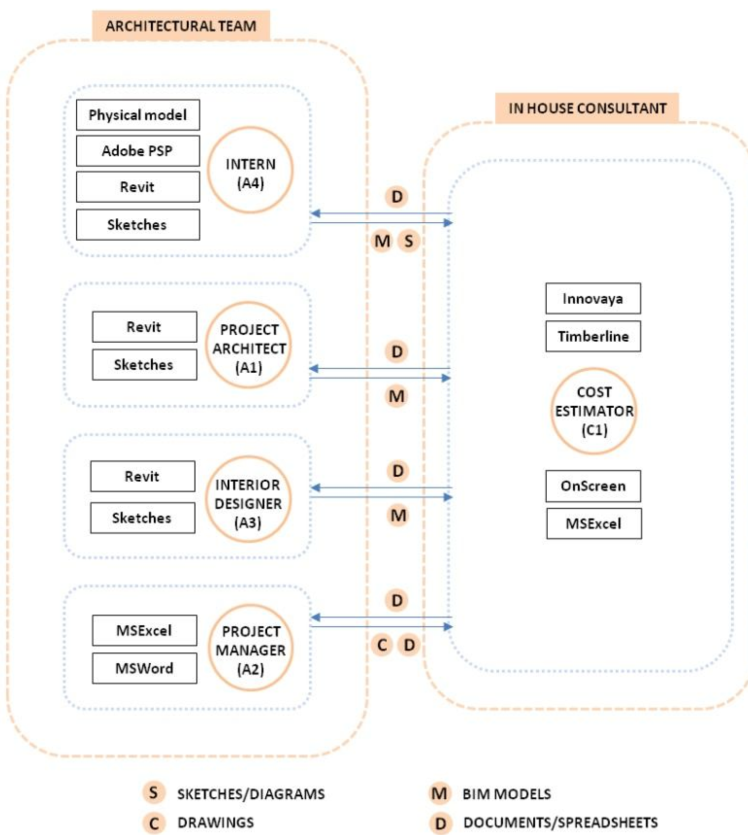

Figure 5.5. Tools and representations employed in the interactions between the architectural team and the cost estimator (C1) in the SG project

Section 5.3.1 involves the cost analysis feedback loop and some of the missed opportunities that emerged in the study. Section 5.3.2 involves the gaps identified between the information embedded in the BIM base model and the information required by (C1) and the reconciliation efforts to fill those gaps. Section 5.3.3 involves the challenges that face the architectural team and estimator during the transition to BIM, and the role of the BIM manager in resolving communication issues and developing robust information exchange mechanisms between them. Sections 5.3.4 through 5.3.6 introduce three events related to the interaction with some of the AEC consultants; mainly the structural and MEP teams. These events identify emergent issues related to the shared space of communication among AEC teams enabled by the BIM base model. Figure 5.6 illustrates the main tools and representations employed and exchanged between the architectural team and the structural and MEP teams in the SG project. The civil and A/V teams were discarded from this figure since they did not use BIM tools in this project.

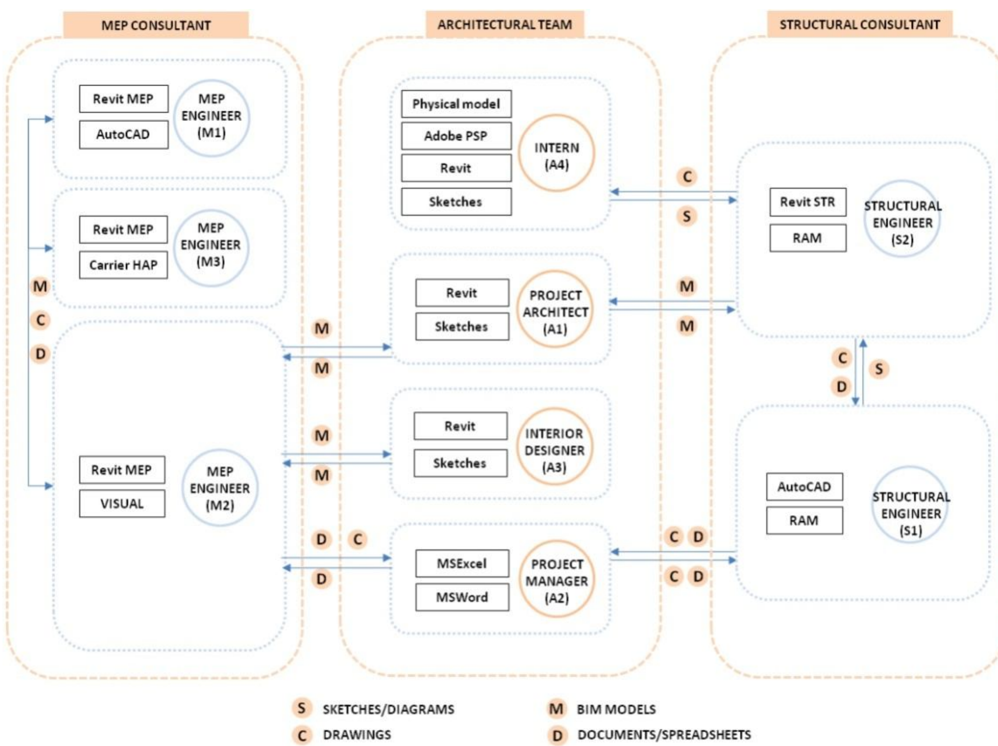

Figure 5.6. Tools and representations employed in the interactions across disciplinary teams in the SG project

Section 5.3.4 involves model ownership and shared repositories of information, and how teams develop workarounds in their model exchange and update process for practical reasons. Section 5.3.5 discusses the sole use of BIM models and the need for additional means of communication such as verbal discussion or additional representations. Section 5.3.6 discusses the significance of understanding the underlying logic of analysis programs to generate reliable analysis results rather than relying completely on automatically generated results.

5.3.1 Event 6: Informing the Design – Missed Opportunities

This event describes the mutual interaction between the architectural team and the cost consultant while discussing the design of a specific element in the courtyard area of the SG project, and its cost implications. (A4) was assigned by (P1) and (A2) to design a cast in place bench in the extension of the courtyard. As she was still learning some of the technical aspects of its assembly and fabrication, she spent most of the DD phase discussing those aspects with the structural engineer, landscape engineer and some concrete specialists and subcontractors. Cost, however, was an overlooked issue in this design process. This resulted in a past due discussion between (A4) and (C1) about figuring out ways to include the designed element in the tight project budget.

As this bench was not an inherent part of the design and was introduced later on in the process where most of the budget constraints were already set, (A4)'s intention was to design something that was as cheap as could be. Her design process, which extended to include sophisticated finishes and cast in place burnished concrete, was mostly through hand drawn sketches which she exchanged with the landscape and structural engineers. She also included the bench in the base model to get an estimate. There was a strong disconnection however between her sketches, design iterations and discussions with the engineers on the one hand and the cost estimating process on the other. The first figures she was getting as an estimate for the bench were around $1000. (P1) and (A2) did not pay much attention to the possibility of building this element or to the low cost, as this was secondary compared to the more important details of the building. As things were heading more towards refining the estimate, (A4) was faced with a very different number than she had in mind at the beginning:

A4: *I designed it in my mind the cheapest way possible – well after estimating it, it turned out that it was 39000 dollars – this is what the subcontractors told us then I estimated it again with somebody in-house [C1] and he said it's probably 15000 but anyway we might not do that because we can't afford anything like that…the thing is that we had it in the DD…for some reason it was estimated at 1000 dollars.*

For her, $1000 was already a nonsensical figure, as it cannot even "*buy a piece of furniture*", but she thought the real figure would be something around $5000 or $6000 and not $15000 in the best case, which was (C1)'s estimate. At that point, she felt the disconnection that was happening between the sketches that she had produced independent of the cost analysis process:

A4: *Anyway I designed something in the end but I'm not sure it's going to happen – now I reached the conclusion that nobody knows what's happening in the hardscape plan that I put together a long time ago through sketches.*

It was almost impossible to include (A4)'s bench in the budget because it was a completely new item. Although the $1000 and $15000 estimates were both generated by (C1), the amount of detail and information that (C1) was provided with at the beginning was minimal and did not reflect the complexity that (A4) expected. At this point in the project, she argued that the bench was modeled and represented in the BIM base model and therefore should have been included in the estimate to reflect what she wanted. Based on that, she asked that there should be allotted money for this hardscape element:

A4: *Actually this was modeled…but anyway after this whole thing I wrote an email to (P1) and (A2) and told them ok we have this thing estimated at 1000 dollars – I mean they encouraged me to design it in the first place but they needed to know where we are – we have this thing that we don't have a budget for right now and was estimated by subcontractors at 39000 – we can bring it down to 15000 – can we get this money from somewhere else?*

The problem here is that, according to (A4)'s claim, the bench was in fact *modeled*. But what does *modeled* mean in this case? Does this guarantee that the *right* estimate could then be produced accordingly? This implies either that the bench was modeled correctly and the estimator failed in his take off process or that it was not modeled properly to begin with and the estimator did not have enough information to instigate his calculations. The latter was the case:

C1*: It's sort of a custom item – it was a cast in place bench that was integral with the slab on grade and it was ground and it was polished and it was self supported and it cantilevered and it had a hole cut out of it and it had a planter coming up – that kind of stuff – and on the drawing it shows as a rectangle like that.*

In the model, (A4) modeled this complex cast in place bench as a simple rectangle without any details, but just as a custom object with no specifications. This was partly because she was not experienced enough with the tool and relied mostly on hand drawn sketches, but did not convey this information later on in the model. Not only was the necessary information not embedded into the model element, but there was also no dialogue going on between (A4) and (C1) since she started working on her design.

(A4) gave (C1) only broad headlines with no specifics, and so he produced an estimate with a very low figure. Upon developing her design and introducing many materials and much complexity, she did not consult with (C1) and went on with the design till the very end. In addition, (P1) and (A2) had initiated the idea of this bench in the middle of the process, just at the beginning of DD, where the budget was already tight and the cost of the bench was not put into consideration. (C1) suggested that the interaction with the architectural team should have taken a different approach:

C1*: That's how the process should work is that the design team says here is what we want to do and then we look at it from a cost perspective and say well I'm not sure you can afford to do that or yeah sure you got plenty of money to do that – if they can't afford to do it they go back and they revise their design and we come back and we look at it again and say yeah that should work from a cost standpoint – and if say they come back and they say the design can't change then we need to change something else so that we can save some money over here so we can apply it to this bench.*

This mechanism that emphasizes constant dialogue and reconciliation should produce, according to (C1), a cost aware design; one that provides continuous feedback to the designer from a cost standpoint and even to the estimator with regards to tracking and controlling the budget all over the project. In order to make an informed decision, he has to have enough assumptions about the element he is pricing:

C1: *Here are my wall types and I'm deciding if the wall is gyp board or not – if it's got one side or two sides – if it's structural – if it's got a bat – if it's rated – so rather than pricing generic walls we got some fairly detailed and it's pretty easy to talk to folks to say here are the assumptions that I've made – are these reasonable assumptions? Specific assumptions but are they reasonable versus if you don't do that then what you get you got a big lot of money sitting there – 50000 dollars – and what does that include? I'm not sure what that includes.*

These assumptions should be at a certain level of detail and not in the form of generic pricing or a lumpsum figure that does not give him any clue in terms of breakdown or how to track it across the project phases:

C1: *Philosophically some people's approach is: landscaping 100000 dollars – throw a 100000 dollars – and philosophically this is where I disagree and where I would rather make a bunch of small guesses – specific guesses and say yeah that all looks right.*

"*Throwing*" a number as an "*estimate*" makes no sense for (C1) in this case, and that is why he needed much more information from (A4) or from any other member in the architectural team in order to use this information as a foundation and infer some additional parameters based on his experience to make "*intelligent decisions*":

C1: *Let the number be the number and it goes back to…do you just throw a big generic wall at it or do you make some intelligent decisions – what do I think this wall is going to be? Obviously I know if it's an exterior or interior wall – if it's made out of gyp board or masonry or something else – probably gyp board – is it in a location where it's going to have to be rated? Yeah it probably will have to be rated.*

These decisions would lead to a reliable figure that (C1) would trust and be able to track and manipulate throughout different phases instead of putting a generic figure in that represents a big black box for him. Even with an expert estimator like him, lumpsum figures are meaningless. He cannot infer if a given total cost is appropriate or not unless he is provided with incremental pieces of information and assumptions about that cost:

C1: *I've been doing this for 20 years and if somebody asks me should 150000 dollars be enough to do that? And I'm like…how much is that 150000 supposed to cover? And then you start saying oh it's 2 acres or whatever so many square feet – well then you start backing into it if it's this many square feet and there is this much a square foot unit cost that should be enough – well if you know that then, why not show that you know rather than a one lumpsum of 150000 – why not show so many square feet and so many dollars per square foot and that's the point of all this.*

Showing those assumptions explicitly and early on becomes then essential for a more transparent process where design decisions can be informed in real time in accordance with budget constraints:

C1: *It protects me or whoever is doing the estimate where you show people this is how much of this I'm assuming we're going to have.*

Figure 5.7 shows a segment of a schematic design estimate prepared by (C1) for the SG project. Although the estimate is at an early stage of design, (C1) preferred to set it up at a fairly detailed level that allowed him to understand and track every line item from beginning to end.

B30 - Roofing		79810.0	gsf	0.00	0.00	$0	**$295,152**
B3010 - Roof Coverings		0.0	sf	0.00	0.00	$0	
	vapor barrier + insulation	0.0	sf	0.00	0.00	$0	
	membrane roofing (modified bituminous)	29015.0	sf	9.50	8.93	$259,010	
	flashing + sheet metal (coping) x10"	402.0	lf	14.90	14.00	$5,627	
	flashing + sheet metal (coping) x12"	913.0	lf	16.80	15.79	$14,413	
	flashing + sheet metal (coping) x16"	66.0	lf	20.50	19.26	$1,271	
	flashing + sheet metal (gravel stop) @ canopy	533.0	lf	15.00	14.09	$7,513	
	specialties/accessories	0.0	ea	0.00	0.00	$0	
	rough carpentry	3894.0	lf	2.00	1.88	$7,318	
B3020 - Roof Openings		0.0	sf	0.00	0.00	$0	
	skylight (gable) x1'6	0.0	sf	80.00	75.17	$0	
C10 - Interior Construction		79810.0	gsf	0.00	0.00	$0	**$974,573**
C1010 - Interior Partitions		0.0	sf	0.00	0.00	$0	
	cmu partition	0.0	sf	0.00	0.00	$0	
	metal partition (composite panel) interior	0.0	sf	37.31	35.06	$0	
gyp board partition	*0A1G x1 :ceiling*	21300.0	sf	3.46	3.25	$69,251	
	0A2G x2 :ceiling	7300.0	sf	4.93	4.63	$33,817	
	0C40G x1 :structure	1360.0	sf	4.52	4.25	$5,776	
	0D2G x2 :4'0 aff	360.0	sf	4.93	4.63	$1,668	
	0F1G furring (spandrel)	1018.0	sf	4.08	3.83	$3,903	
	0F1G furring :ceiling	2436.0	sf	3.40	3.19	$7,783	
	0S1G x1 :structure	6502.0	sf	3.68	3.46	$22,484	
	0S40G x2 :structure	7076.0	sf	5.15	4.84	$34,243	
	0S49G x2 :structure w/batt	47002.0	sf	5.88	5.53	$259,695	
	0S1G x1 :structure w/batt	1174.0	sf	4.42	4.15	$4,876	
	1CH48G x1 :structure w/batt	4972.0	sf	8.50	7.99	$39,712	

Figure 5.7. Segment of SD estimate prepared at a detailed level by (C1)

5.3.2 Event 7: Reconciliation – Filling in the Gaps

The process of adjusting the design to fit within the allotted project budget was a very critical and exhausting one. (C1), (A2), and (A1) first came to realize that there was a problem with the budget at the end of the schematic design phase, when they found that the project was 60% over budget. This was shocking for the architectural team, but expected for (C1) who was always complaining that there should be constant dialogue between him and the team in order to reconcile cost early on and as a continuous feedback process rather than an afterthought. The natural outcome of their discussion was that a process of redesigning was inevitable:

C1*: (A2) and I sat back here and played with these numbers and tried to get with an eye on the bottom line trying to get this thing into budget – but she went back to (A1) and the designers and said here are the percentages see what you can do with them – so ultimately he [A1] came back and said here is what we can do – here is a design that we like and here are the percentages associated with it so we plugged those in and tried to make everything work – it's how they all should work.*

(A1) provided (C1) with the new design together with the quantity take off generated from the Revit schedules. (C1) already had some of these percentages and figures early on in the design, but there was a disconnect between the development of the design and the estimation process for more than two months, as the team was more involved in adjusting their design and did not pay attention to cost as an important factor. (A1) thought that it was so difficult to provide (C1) with schedules from the BIM base model at such a preliminary stage of design. Although it was a waste of time and effort, (C1) had to go through the automatically generated Revit schedules as well as his own quantity take off mechanism as a double check to study how everything could fit back within budget. He set up his spreadsheets in a way that made it easy to manipulate and have "*control*" over the numbers, and therefore adjust relative percentages of exterior façade materials to bring things back to the assigned budget:

C1*: I measured the brick veneer and measured the stucco and I measure the metal panel and I measure the storefront curtain wall and we were over budget so then what we* *started doing was well this is how much exterior skin you have then let's decrease the quantity of expensive skin let's increase the quantity of less expensive skin.*

It therefore became a process that was totally dependent on modifying relative weights and percentages of exterior materials to come up with "*sensible*" numbers for the overall project cost. For (C1), this was a process that worked for him regardless of the technology used, but was more dependent on his personal experience. He knew that he could have done this process in a tool like Timberline for estimating, but Microsoft Excel was sufficient a tool to carry out the same steps. In addition, he felt more confident because he had his own calculation methods embedded in those Excel spreadsheets:

C1*: As a design tool it was helpful because that tells the designer ok we priced 32 percent of this exterior skin with brick veneer – 35 percent of it being stucco – 9.5 percent storefront – 13.5 percent curtain wall – so if they are going to deviate from those ratios then they are going to have to find a way to do it…they are going to have to come in here and they got to increase their quantity of inexpensive wall and decrease the quantity of expensive wall.*

According to (C1), this process was not about the technology as the technology just "*gives you the data*" whereas the decision making process in estimating is more about "*how you interpret the data*". So for him, he was less concerned about the estimating process, where he had his own tools and calculation sheets that he trusted more than any automated cost estimation software. He was more concerned about quantity take off although it seemed like a straightforward process. This concern was always more in earlier phases of design, where the architectural team is still developing the design, with a lot of hidden variables and unknowns, and is not yet comfortable with sending out the model to the estimator.

(A1) was reluctant to send (C1) the base model for his cost review throughout the schematic design phase. He believed that estimators in general have high expectations since Revit can generate schedules at any given instance, but that it was not necessary at this stage to do so. At the same time, although (A1) used Revit, he did not necessarily 1) model every single element, and 2) embed the information that (C1) required for the building elements. For (C1), this demonstrated that (A1) and the team were not yet committed to many design decisions:

C1: *I guess they don't want to be held to a decision that they made early on because they think well I don't know all this stuff whereas they can give me this wide description of a wall but ultimately the way that I price – what I do is I look at this line description and I say ok maybe it's like this – this is in my opinion fits the best description.*

What (C1) needed from the architectural team was not an accurate figure per se but at least some information concerning building elements that leads to a best guess informing (C1) about his estimation process. For him, if one or more members of the team have specified the material of a certain wall for example but have not embedded that information in the model, then why not inform him that they have made that decision? (C1) was usually more willing to have an ongoing conversation with the team about these decisions to provide parallel feedback and to avoid such drawbacks related to the budget, but they still could not cope with that rate in their communication with him:

C1: *I'm open to them – I want them to tell me if it's right or wrong but unfortunately many times they don't look at it and they just say oh ok.*

According to (C1)'s experience with the team, they typically do their modeling and expect it to magically meet the allotted budget, which turns out not to be the case. Rather than working on understanding what parameters or other pieces of information that (C1) needs to carry out his process accurately without countless assumptions, they tend to think of estimation as a discrete process. They are usually cautious not to take any decisions especially when they are at a preliminary stage, but (C1) claims that there are "*rational assumptions*" that can be put forward, and they should be the ones to take them as they are more aware of the design than he is. He ends up making those assumptions to a certain level of detail that suits his estimation process:

C1: *When I'm doing a schematic level estimate I might go ahead and choose what kind of partition – if they are just drawing partitions and they don't tell me what it is but I'm making decisions about whether I'm putting masonry partitions around elevator shafts or around stairwells or I'm putting rated shaft wall here and I'm putting non rated partitions that only go to ceiling in these locations – I'm making those very detailed* *decisions very early on for pricing purposes – that seems to freak out designers because they would say well I don't know what it is – well personally I don't know what it is either but I'm making rational assumptions.*

For (C1), it is only when the architectural team is faced with shocking analysis results, primarily being off budget, that they start to realize the severity of the situation and that they should work on modifications or redesign:

C1*: Here is a comparison between a DD that somebody did for us out of house and our SD and it's pretty easy to see…the idea is to break your estimate down to where you can see where the big changes and where the problems are – and that sort of what tells you what you need to work on – most architects won't change anything until you show them that because they want to hope that what they draw will come in out or under budget.*

The architectural team's feedback was still not receptive enough to (C1), because they could not fully identify with what it is that he needed from them specifically. This became disturbing for (C1) as he expected them to be able to recognize and embed a minimum number of parameters for the model elements and export their models with a fair amount of information relevant to his estimate:

C1*: I said how do we get quantities out of Revit and so they said well we can print out these schedules but then they were like what do you need to know?…they kept coming back to me wanting me to tell them specifically what I wanted versus them being able to just print out a report or a spreadsheet or a schedule from Revit – so that was a little bit of a hassle.*

Even after exporting such information, it was hardly ever to the level of detail that (C1) needed and was very basic. (C1) had to spend a considerable amount of time to fill in the gaps in the information coming from the model, adjust the numbers coming in, and format them in a way that serves his purpose:

C1*: Once we got out the information it was just very generic and not that useful but some of the information that we got we could use – but then it took to be able to get it in a way or to manipulate it so that you can put it into Excel and use it…total alike items up, group, sort, do all that and then jump through all these hoops to get it to the final point.*

This inconsistency and random method of work led (C1) to think about ways that can reduce the gap between his understanding of the model and the missing information from the architectural team. His primary goal, which he decided to take on for further projects, was to establish a reliable "mapping" method to resolve inconsistencies. His focus was on developing robust naming conventions of building model elements and interrelationships that help fill in these gaps (for example, establishing a fixed database of names that thoroughly describe elements such as doors, walls, ceilings, etc. and their different types, attributes and unit cost prices):

C1: *Conventions that are descriptive enough so that anybody that goes in the library can understand the difference between this door and this door and this door or even our wall tag system…I don't think the problem is with overlap – I think the problem is the gaps.*

5.3.3 Event 8: Transition Challenges – BIM Manager as Liaison

(C1) had been using the OnScreen take off software and Excel spreadsheets to generate his estimates using PDF exports from Revit. Mostly encouraged by (B1), they both saw the need for a gradual transition that allows (C1) to extract quantities directly out of Revit schedules and use another advanced cost estimating software package that allows him to look at data in multiple ways. This was seen as a "*transition to BIM*" with the primary and pragmatic goal being enabling (C1) to save time and effort in his estimating process, engage in more analysis and feedback with the architectural team, and have more time for working on other projects within the firm:

B1: *Right now he [C1] feels like he spends a majority of his time and I'm talking majority like 90 percent measuring drawings just doing take offs – so we're thinking well if we can reduce that virtually even if it's not 90 percent if it's 50 percent that gives him a lot more time to do actual estimating… you have the potential to have more analysis along the way.*

(B1) also knew how (C1) could not easily trust the figures and quantities coming out of the base model because he would not be in full control of the mechanism generating those figures. The fact that (B1) was aware of (C1)'s method, perception and way of thinking, was an important factor in the approach they both adopted to initiate the transition to BIM tools:

B1: *From Revit doing a simple export to Excel – it meant creating a schedule in a certain way – again the limitations of Revit scheduling…I would be suspect of him [C1] if he just* *took it fore granted to be right the first time…it may give it in a way that his spreadsheet wouldn't accept it.*

Both (C1) and (B1) were skeptical however about what those BIM tools would have to offer and whether it was a seamless process. They knew beforehand that it was not simply an "automatic" quantity extraction or estimation process, and that it could involve even more work to get the process to work:

B1: *What we have no clue is how hard it's going to be to make the Revit model produce that information…I mean it's not perfect by any means – it's cumbersome and not the easiest way to do to get that information.*

(B1) was more confident in the information exchange capabilities among the different BIM tools than he was with the team essentially following the right procedures to get that process working. He was trying to play the role of the liaison between (C1) and the architectural team. (C1) had his own set of information that he needed and formats that he desired, and the architectural team needed to know what those were, but both were unsuccessful in communicating that. (B1), being an IT specialist, spearheaded the effort to fill the gap between the two, as he felt he had to intervene to resolve this miscommunication:

C1: *(B1) and I will have to talk to make sure that they are giving me the information that my assembly needs…we got to talk to and agree on what goes in each of those – I've got to let him know what I need for an assembly and then he's got to let me know if they can do that or not – if it's not reasonable, if something I'm asking for is going to cause a lot of heartache or a lot of extra work to do then we have to find – I have to find a way to work around it.*

(B1) and (C1) chose Innovaya and Timberline as the cost estimating software package that they would employ together with Revit. Innovaya has the ability to export Revit schedules in spreadsheet form, visualize the 3D model in terms of its associated unit price, and map Revit model elements to cost line items in Timberline to instigate the estimating process. Establishing and mapping conventions was the most important factor in the standardization effort that (B1) and (C1) worked on together:

C1*: What (B1) and I are in the process of doing is trying to standardize a lot of these things so that we can get enough information just into the name or the label so that when I'm mapping and I'm linking to this side in Revit or Innovaya saying this equals my Timberline thing over here it's pretty clear what's what…we talked about naming convention for doors how we would - what we're going to call these things and getting enough information built into here but at the same time having more detailed information.*

As this effort went on, there were issues that were considered a "*no brainer*" such as basic parameters of model elements, and other issues that required a certain level of detail that (C1) needed to develop his assemblies in Timberline accurately and proceed with his approach. (B1) had to make sure that the degree of description of those issues in the base model conformed to the assembly description in Timberline:

C1*: On the Revit side when we draw a door it has to sort of contain – it doesn't have to contain all the same things that I put in the cost assembly but it has to be described to the degree that I can see it and know that ok in Revit this door and frame is my door and frame assembly over here in Timberline and so the big thing is to – when (B1) and I were talking about it is – how much detail or how many of those items do we have in the Revit library and also in Timberline assembly.*

Both Innovaya and Timberline offered a lot of advantages for (C1) such as efficiency, the ability to visualize building model elements in terms of their unit cost price in an interactive fashion, and the automatic extraction of quantities and generation of project costs. Some challenges still remained however for both (C1) and (B1), mainly the resistance of the architectural team:

B1*: Project teams all they will need to do is publish some type of whatever it is that Innovaya needs to read – so it's almost like printing to pdf – they don't really need to know what is happening they just need to do it – what we need them to do is to draw correctly.*

Besides the steep learning curve, proper modeling, or "*drawing correctly*", was the main challenge for the team in this case. This included primarily accurate 3D modeling but also careful input of parameters and proper use of naming conventions so that the appropriate "mapping" would result in a reasonable estimate:

B1*: If they create a family of some sort it's got to fit into that framework somehow – if they create a new wall they need to understand that you can't just name it anything – it's* *probably going to have to have something meaningful that will work with Innovaya and that's going to be the challenge for the drawers.*

Other challenges were related to the tool itself and the level of confidence that both (B1) and (C1) had in its methods of extracting reliable information and whether that would affect the overall credibility of the process. In other words, could (C1) partially rely on some data coming from the tool or would he completely turn down the tool to begin with as a result of this mistrust?

B1*: There are going to be some things that I'm confident we're going to be able to – it's going to count doors and windows and I'm almost I'm fairly confident even with the walls – where I get nervous is things like casework and other things – but the question is: is it an all or nothing – can he [C1] say ok these are the things that I'm confident about when I get it from Revit and I'm going to use those in my estimate and this other stuff I'm going to look at it but I'm going to actually do it in a different way over here in Timberline.*

During this investigation of (C1)'s perspective, (B1) tried to put himself in his shoes and imagine how as an estimator he would look at the model from a cost standpoint. There were clearly a lot of discrepancies between the two views. In the process of selecting a tool that would be, in (B1)'s view, appropriate for (C1), a lot of issues came into play. First, (B1) tried to find a tool, like Autodesk QTO, that would feature a mix of two components; automatic extraction of quantities out of Revit and at the same time allowing him to mark PDFs of the extracted take off as he used to do in OnScreen. (C1) however was not in favor of that mechanism. (B1) then recommended using the Innovaya visual estimating software based on his assumption that adding a graphical component to the process would enhance the take off and estimation process:

B1*: I don't really understand how they [estimators] look at stuff to begin with – when I think of it I think if I can see it graphically then it starts to make sense to me…to me it would seem like it would be a better thing…and I would think from an estimating perspective that if you saw a model of what is going to be built you can say well that's going to be complicated to build or that's going to be more expensive – it seems like it would inform you more and that it would help you rather than hinder.*

This assumption was augmented by his observation of the nature of interaction between (C1) and the architectural team. To (B1), if so much confusion was happening because the medium of representation was not rich enough for (C1) to visualize quantities of materials and their associated prices or did not contain all the information he needed, then why can't a 3D environment enhance that?

B1: *I think he [C1] does spend a lot of time asking questions of the team based on what he is seeing in these two dimensional drawings – and I can't help but wonder if a three dimensional model would answer some of these…you could kind of start visualizing materials inside of that and see that's there and this is there but I don't see it in my estimate or I don't see it in the information that is coming out of Revit.*

For (C1) however, this was not the key issue. His main concern was getting the architects to provide him with sufficient information, in any shape or form, whether it was spreadsheets or a 3D visualization and automatic extraction of information. The technology aspect was not his main focus, but he was worried about getting a reliable set of quantities from the model in a seamless manner. Once that is achieved, the rest was all up to him since it is his domain of expertise:

B1: *Estimating – there is an art to it – and why you would choose this person to do estimating over anybody is because anybody can look at a book and in RSMeans to see how much something would cost but I think there is something to it more than that – there is this what's the world doing and what's the economy doing.*

The main question then was how to get the model to generate accurate and reliable quantities for (C1), or more precisely how much of the model can he use for generating those quantities? This was his main goal, as he was sure that a 100% "automation" of this process was never possible, and that his intervention and best judgment was always inevitable:

C1: *How much of it are items that you can sort of standardize in Revit and standardize in Timberline and plug that out…if you can get 50 percent of your quantities out of your model which I think is optimistic but say that it ends up being 70 percent then there is still that manual take off – there is still a manual element to the estimate – the only way that you can automate it entirely – well you couldn't automate it entirely because architects are never going to draw the entire building – they are not going to draw every part and piece that goes in the building.*

To realize what can be really "automated" versus what needed intervention, (C1) had to identify in the Timberline assemblies he was building three basic categories: 1) the line items that are considered "*low hanging fruit*" such as door counts and wall areas, 2) those line items that can be extracted directly but required some assumptions from his side, and 3) those line items that are never modeled in the first place but have to be included in the estimate, and those have to be embedded manually by (C1):

C1*: Figuring out which items are easy or low hanging fruit – then which items you can make assumptions on and still automate them or make some general fairly accurate assumptions still have them automated – then those items that you are always going to take off manually.*

To set up these categories, (C1) had to build complex assemblies that take into account some of the items that are not originally modeled in the BIM base model. This was the category with the maximum struggle and that required work from both sides. (C1) had to develop ways to get that information somehow by "*asking questions*" in his custom built assemblies in Timberline. This meant that he required more details from the architects about the parameters that had to be embedded in the base model, whether the element itself was actually "*drawn*" or not:

C1*: You got a roof and you got a coping coming down and maybe you can build into it the fact that this roofing membrane comes up and turns up a foot or 24 12 inches – do you draw your counter flashing that goes over here? Do you draw all the other things that are associated with that detail? I mean is all that information built into the element? I just always see that there are going to be certain things associated with this detail that aren't going to be quantified on the drawing you – it will be labeled and then we call it out here in a section but will it be built into the edge of that slab or that exterior wall?*

Through the continuous refinement and development of these assemblies, (C1) believes he can be more confident in the take off process and ultimately ending up with a higher percentage of reliable information from the base model. Although never 100% reliable, it would help him trust the figures more, provided that the architectural team performs the modeling task correctly:

C1: *Through assumptions or assemblies or parameters that we can build, some of these things that aren't drawn into these model elements – so maybe ultimately this number ends up being 75 percent… I don't think that that number will ever be 100 percent.*

Figure 5.8 illustrates how (C1) worked with parameters in the BIM base model to arrive at reliable cost parameters for his estimating process. When using OnScreen (figure 5.8b), most of the parameters are not embedded in the PDF and require creating a considerable amount of assumptions and a lot of manual input, since many building elements are not modeled. With Innovaya and Timberline (figure 5.8a), most of the effort is shifted to making sure that the correct modeling and parameters are embedded initially in the Revit model. There still remain some assumptions for line items that cannot be determined at an early stage, and manual input for elements that "*will never be drawn*" according to (C1).

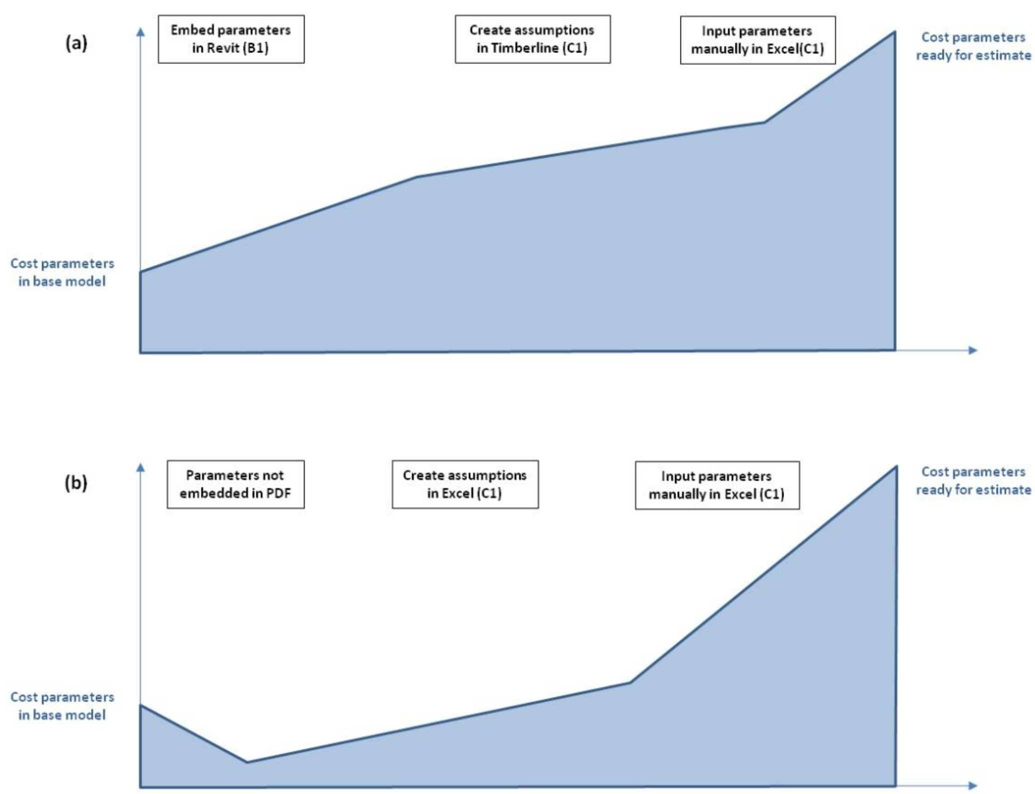

Figure 5.8. Relation between parameters in BIM base model and reliable cost parameters for estimation: (a) using Timberline and Excel from Revit, (b) using OnScreen and Excel from PDF

To reach a 100% reliable estimate, the assemblies would have to include, in addition to a "perfectly drawn" model, very long lists of markups and parameters that are not always easy to "fill in". The tool then becomes so powerful for (C1) that it is more confusing and hard to figure out because of the excessive setup and variables. Too much "*automation*" for him is not any more comfortable and does not add that much confidence to him. He believed that a more successful model of this automation involves creating libraries for building elements have a level of description suitable for each phase of design:

C1: *I keep using the word automate there probably is a better word – but if you want to use some of the information that's in your Revit model then it seems like you have to develop different libraries – a schematic library – a design development library – a predesign library…I'd rather have one very detailed library where it tells me that a gyp board partition goes from floor to structure, it's got two sides to it, it's got insulation in it, it's got 5 eighth inch gyp board – and at SD when they show me the wall and I look at it I decide I'm going to use that very finite description of what that element is.*

5.3.4 Event 9: Shared Repository and Model Ownership – Pragmatic Workarounds

In this specific pattern of information exchange, the architectural team worked with the MEP team on coordinating lighting fixtures in the BIM base model. Several practitioners were involved in this process. First, (A1) and (A3) would insert their proposed light fixtures in the BIM base model that is updated and uploaded to the project server once or twice a week. At the same time, (A3) would meet with the lighting sales representatives to select suitable light fixtures. These would be passed on to the MEP firm in physical meetings or via email, where (M6), under (M2)'s supervision, would become involved from the electrical engineering standpoint and start performing the necessary photometric analysis using the *Visual* software package. Then the MEP firm would insert their adjusted light fixtures according to their calculations into the model. One of the main issues with coordinating elements such as lighting fixtures in Revit was the ownership of these elements in the model. The fixtures that were inserted by (A1) or

(A3) in the model were 3D models but were just placeholders, pending the actual specifications from the electrical engineer:

M2*: They [architectural firm] put in their architectural model light fixtures with no information – we have to take that out and we replace it with our model in the same place but that now has information in it that we need in there for our model – so it's the same concept – they put a placeholder in and we have to replace it with an MEP model – so the ownership is on our model for our stuff even though they show it on theirs – as we go back through and redo calculations we may shift a light fixture to perform better – then (A1) would just move his over.*

Two distinct fixture entities were therefore instigated: 1) "*architectural model light fixtures*" which (M2) described as "*placeholders*" that had "*no information*", and 2) "*MEP model*" light fixtures which contained the engineering "*information*". The information exchange process between the architects and the MEP engineers revolved around these similar but unique entities. Two intertwining loops of "proposal – relocation" and "formulation – replacement" were continually carried out by the architectural team and the MEP team respectively. As (A1) was primarily in charge of model ownership and coordination between all participating disciplines in the project, he planned the process of coordinating light fixtures with (M2). Knowing that there are several approaches, and having tried many in previous projects, he selected one for this project that does not rely on one single team "owning" the lighting model elements, but rather using the base model as a shared space that contains both fixture entities; the architectural and the MEP fixtures:

A1*: That has always been a big issue in Revit of who owns what…for instance do we own the lights? essentially you guys (to M2) would like to own the lights because you have so much more information in there – what I've found is…that we have our lights and you have your lights and that you turn ours off in your model and we turn yours off in our model.*

Although (A1) showed an understanding of (M2)'s preference concerning "*owning the lights*" which represent the MEP model fixtures, he based his argument on previous experience with similar projects. At the same time, he did not use the direct implication of Revit's functionality which allows ownership of model elements to one of the participating teams. Instead, he developed a workaround that makes use of the tool as a shared repository of information and enables both parties to view their light fixtures either one at a time for their separate tasks or simultaneously for coordination:

A1*: Now the bad thing about that is you have two lights but it's really easy to coordinate – you can go in and turn on both lights and do a quick look.*

This flexibility was enabled by the ability to set up *check* views that have both representations displayed and *printing* views that have a single view of the model elements. This approach was satisfying for the MEP team, whose task was providing the updated light fixtures. (A1)'s task however was more complicated. According to (A1), (M2) and the MEP team place the fixtures based on their calculations, but there still remains the task of adjusting those based on how the architectural team "*wants it to work*", as there is a lot of equipment that has to be placed and managed. In addition to relocating the updated fixtures in the model, (A1) had to coordinate all other models including the structural model and the internal updates within the architectural team. This coordination effort again required selecting among a group of approaches, ranging from redlining hard copy drawings in physical meetings with the consultants to using 3D conflict checking software packages. This was closely coupled with the modeling methods that (A1) used and advised the consultants to use in project meetings:

A1: *We'll try to avoid a lot of modeling in there – if it's not necessarily being modeled I don't think it needs to be drawn in 3D – usually if it's seen in two views I'll model it – if it's only seen in one view it can be drafted.*
A3: *Can you give an example where you wouldn't want…?*
A2: *I'll bet they (the consultants) are a lot less inclined to do extensive modeling then we are (laughs) – it's probably more directed to us.*
A1*: For instance you can go in there and get a projection screen that has a crank and all the stuff on there but all you really need is a rectangular box and that's it it's very simple – you can go and create round lights and round fixtures and stuff – you don't need to – so we're going to avoid that just to keep the model as small as possible.*
E1: *But you would model like the connection box he was talking about for flat screens? And create families for that that can be dropped everywhere?*
A1*: Yeah I think it will be – for instance if we do a flat screen panel I would create a rectangular box where all the wall in elevation has got drafted rectangles so when you are in elevation view you will see the boxes in elevation view but you won't see them in*

plan view – you might see the symbols for the boxes in there but we aren't going to model real boxes and wires and blocking and all that stuff.
V1: *That's what we found out that most of our stuff doesn't end up in the Revit model – I mean there's few elements that actually end up I mean – we discussed that.*
A1: *You know a lot of it doesn't have to be modeled – so the more you model the more memory it takes the slower your computer works trust me – when you sit there and wait for your computer to work it takes a while.*
M2: *I guess I see that there will be some – we're just going to need to coordinate with you – we'll take a shot at what we think we need to model and make sure what you are going to see.*

Although the project was not exceptional in scale, (A1) preferred to reduce the amount of modeling and keep the base model as simple as possible to avoid computational limitations. Most of the consultants were in favor of minimum modeling, more than the architectural team. This however presented a challenge for coordination, where the notion of having a "complete" model that can be fully checked for inconsistencies and clashes between different model elements became questionable. (A1) decided to use DWFs instead of using a conflict checking software to manage the clash detection process. This was near the end of the construction documents phase. He would print the entire set as a DWF file, mark it up and then import the markups back into the sheet view of the Revit base model so that the consultants would pick up the redlines as they move forward. Although he was willing to use a conflict checking software such as NavisWorks, he believed that there was a lot of redundancy in the tedious process of using such a tool. A thorough clash detection would not guarantee a full resolution of errors or issues, as contractors would perform different procedures based on their interpretation and their own version of the base model:

A1: *Still no matter how careful you are about checking everything the contractor is not going to build it that way – they will get it pretty close but you are still going to have to figure out issues.*

At the same time, (A1) was not comfortable with the overwhelming number of issues and violations that show up in a conflict checking report, making it impossible to follow and requiring that the consultants should meet anyway to discuss the key issues. This was contradicting to (B1)'s point of view, who thought it was a waste of time not to take advantage of such tools for conflict resolution. He believed that the consultants "*cannot flip back and forth and understand in their mind where everything is going*" no matter how long they have been doing that process or how experienced they are:

B1: *It's just much clearer to yes they have the 2D drawings in front of them but they also have the three dimensional and so they can look at it identify mark it whatever see what needs to change about their drawings.*

(B1) still believed though in the importance of physical meetings to resolve conflicts in the base model, but that these meetings should be very focused and efficient in order to figure out the most salient problems with the model and suggest ways of resolution. Unanticipated problems often emerge in these meetings as a result of resolving initial ones, and that is why physical meetings with all consultants around the table become necessary. He did not encounter however many architects and consultants on other projects in the firm going back and doing other rounds of clash detection, and that was frustrating for him because of the many unexploited potential benefits:

B1: *I think that's something that has come out of BIM that I can't imagine not doing that – to me that is truly the low hanging fruit – it's not hard to do – it's quick it's easy – you build the model, they build their model you put them together, and even if it shows you things that you knew were problems anyway I guarantee you there are a certain number of problems that are going to be identified that you wouldn't have gotten – and I just couldn't imagine not doing that part of the workflow.*

5.3.5 Event 10: Conflict Resolution – The Need for Supplementary Communication

One of the features that the architectural and structural teams attempted to implement in their coordination process was the "copy/monitor" functionality in Revit, which allows either team to check if specific model elements have been modified or relocated upon each instance of model exchange. (A1) and (S2) were mainly involved in this coordination process. (A1) was in charge of making the settings for the base model and monitoring modifications in elements such as column grids, levels and slabs. The premise was that both teams become instantaneously aware of model updates, especially as the model grows in size, and carry on the design based on the latest modifications.

This was also proposed by (A1) as an alternative approach that takes into consideration the problems associated with model ownership, where the routine flow of the process could be at risk. Frequent stops were anticipated as a result of having to "relinquish" some elements for the other party to take control over and work on:

A1: *It gets to be a problem when you say somebody owns this and then you got to call and say can you move this duct or this register one foot or something – sometimes it's easier if we just all own – until Revit figures out how to get all that coordinated I think this is the best.*

(A1) therefore preferred to adopt the "copy/monitor" approach to avoid these frequent disruptions in the process and rely mostly on the notion that the model would "tell" them what needs to be adjusted upon each model update. He still thought that the tool did not entirely resolve this issue, but that this approach would be more satisfying and quicker in terms of dealing with the regular weekly model updates. (S2) was already new to the tool and was still struggling with its functionalities. He got help from (S3) throughout the project but was still faced with many hurdles, including the "copy/monitor" functionality. His first experience did not satisfy his expectations:

S2: *You do a copy monitor and you get a new model from the architect and it tells you instances of Revit changes – it tells you something has changed – it just says something is changed – you're monitoring let's say you're doing grids columns edge of slab and openings also and it just says something has changed.*

At the beginning, he experienced technical difficulties, where he would try to explore what the exact change was by looking at the details related to the specific model element ID, but the entire model would highlight and the same ID would show for all elements. This was also the case with some of the engineers in the firm, who suggested some file settings should be adjusted, either from their side or from the architect's side. But it was more than a technical difficulty:

S2: *Philosophically it's great but it can't pinpoint what's changed – like if the edge of slab has popped out an inch from point A to point B it needs to highlight that area and tell you hey the edge of slab from here to here has changed but it just doesn't do that yet – it just can't do what it is intended to do – it's supposed to tell you exactly what has changed.*

The issue was more related to how the tool communicated these changes and whether it was a sufficient medium or not. (S2) started to gradually rely less on the "copy/monitor" functionality upon receiving a model update, as he realized he did not "*know*" if a change occurred if it was not mentioned explicitly, especially with the frequent updates that were taking place twice a week on average in the design development and construction documents stages:

S2: *We got to the point where I was like hey (A1) if something changes just let me know just tell me because I'm not going to know unless you tell me – if you move an edge of slab or if you change a grid you got to tell me because I'm not going to see.*

At some point in the construction documents stage, (S2) preferred to stop using "copy/monitor" and rely entirely on verbal communication, which was apparently becoming inevitable, instead of trusting the tool to acquire the necessary feedback:

S2: *We just had to pick up the phone – I mean we just had to talk to (A1) and (A5) and just say tell us what you want what's going on or where things are changing…especially with the stair on the west side of the building – it was changing and they wanted to move some columns…so we just needed to coordinate it that way – I prefer talking to somebody instead of relying on the software to tell me what has moved and what hasn't moved.*

(A1) shared the same point of view, as he believed that the tool, however sophisticated it was, could not "*magically*" inform the teams of changes to the base model. Rather than "automating" the process, he believed email or verbal communication through the phone, and sometimes even physical meetings, were necessary methods to communicate those design iterations and updates to the model:

A1: *Just because the tool is there it doesn't mean we use it all the time – we still rely on talking to each other and emailing to make sure that everybody has got everything covered because you can't just sit there and hope that the Revit model will magically tell the engineer or tell us that something has changed.*

This was an unmistakable fact for (A1). He realized that the sole dependence on the software was never sufficient for coordination. (S2)'s expectations however were higher, partly because he was new to the tool and its use in practice. He thought that the tool would "*flatten*" these issues and that the changes would be resolved in a semi-automated fashion:

S2: *I had to call (A1) and say hey – we just talk through it and decide what we want to do – say hey can it be – can you bump the edge of slab out here because the beam flange is wide – that kind of thing – whereas I thought Revit would kind of flatten that somehow – so there is still a lot of coordination that has to be done – and I don't know if the people who created Revit the end goal is to cut down on that and just rely on the model but I'm not going to do that.*

This led (S2) to not only question the ultimate purpose and efficiency of the tool with respect to coordination across teams and disciplines, but also doubt that the tool conveys the intended purpose of the designer at the other end:

S2: *This stair starts from the third floor and goes up to the roof and they flipped it – (A1) flipped it and the model shows it flip but I still called him up…hey I just wanted to double check did this flip…I'd like to hear it coming from him – I just don't want to do the work and go in and flip it and change my RAM model and go in and change the Revit model and then (A1) would say oh I don't know why it did that – it shouldn't have done that – so I don't care how advanced it is I'm probably going to pick up the phone if something changes like that to double check…I'm not going to put my neck down there on the line for Revit.*

This raises again the issue of mistrust, where operations and workflows have to be "*double checked*" by means of supplementary communication channels, which are not necessarily technologically advanced, to establish full confidence in the transferred information:

S2: *A couple of times I would call (A1) I would say hey we talked about this – putting those in the model – is it this? And he'd say oh I don't know why it's doing that – it's not supposed to – and I would say ok I'm glad I called – or he would call me and he would say you know these beams are showing this elevation I don't know what happened.*

The fact that the exchanged model contains information that is never 100% reliable sounds discouraging. Relying on other modes of communication for verification however is not necessarily more assuring. It raises more questions than answers: Which is more accurate; the information read from the model or the anecdotal information that is communicated verbally? What if either party misses a piece of information in their conversation or forgot to point out all the changes in the model? What if there was an element that was wrongly modeled and the designer did not point it out? What about misinterpreting information that is communicated on the phone or via email?

The counter argument, which (B1) pointed out, is that although most teams start using the copy/monitor functionality but eventually abandon it, there is an advantage which is allowing the teams to come together to discuss the issues and conflicts. The goal then is not spending minimal time performing a standard clash detection procedure, producing a report, shipping it to other participants, and hoping that that report solves everything. The tool here becomes more of a facilitator, where the value resides in highlighting the issues and enabling participants to meet and resolve the issues collectively:

B1: *Copy and monitor whether you trust it or not it's telling him something is there – and he calls on the phone – it forces people on the team to talk more to each other – it could be a good thing even if it doesn't work that well – if it just says you need to talk to somebody – the real benefit is to get people in that room to go over those clashes and come to a resolution on them.*

5.3.6 Event 11: Analysis of Model Data – Unraveling the Black Box

This event involves how participants representing different entities produce varying analysis results from the same building model generated by the architect and interpret information slightly differently. In this event, (S1) and (C2) both received the base model from (A1) at the end of the design development (DD) stage. Both were asked by (A2) to generate a cost estimate for the structural component of the project at this stage. Some discrepancies in the cost analysis results were identified.

(C2) was an outside cost consultant that the architectural firm would often subcontract some cost estimating work to when (C1) had too many projects going on. He worked extensively in the construction and cost management business and established his own relatively small-sized firm. (C1) usually worked closely with (C2) not only through outsourcing parts of or whole projects but also through regular consulting on estimating.

At the same time, (A2) valued (C2)'s opinion and was comfortable with him being on board any of the architectural projects she was in charge of.

(C2) was an expert construction manager and estimator but not so proficient in advanced estimating software. His team used digitizers to extract quantity take off from hard copy drawings. He was convinced that this method of estimating was more accurate than relying on take off from BIM models as he considers it a "*junk in junk out*" process. As described by (B1), he was someone who "*has done it some way for 30 years and he's not going to change*":

B1*: What they [estimators in construction companies] do is they go out and hire somebody that's right out of school that knows how to use the software but maybe doesn't understand the whole process…they'll hire somebody and get him to come in and look at this model and kind of look over their shoulder and say give me this give me this so that I can do what I need to do…I question how much they [hired tech savvy drafters] really know about construction.*

This introduced one of the internal discrepancies in the construction management firm, where there was a dilemma between two subjects of concern: the non-tech savvy cost estimator who knows very little about model based cost estimating software, and the tech savvy drafter who knows very little about construction and estimating.

On the other hand, (S1) was a structural engineer with a background in mechanical engineering and a masters degree in structural engineering. He has been working at the structural engineering firm for over 16 years and was experienced in both concrete and structural steel projects. He was more involved in what he calls "*specialty architecture*" where there is more focus on "*architectural appeal*" rather than just structurally sound buildings. (S1) used the RAM structural package for his calculations and analysis. As the "most widely used for conventional steel framing", he would use it to analyze and track different building loads as well as develop a cost estimate based on the quantities it calculates:

S1*: RAM has an estimating component to it that I feel comfortable with – and I just haven't mined the capacities of Revit yet to make sure that I feel comfortable understanding what it's considering – so as time goes by I'll dig a little more into it*

[Revit] once I understand how I think it makes its calculations I might be a little more comfortable using that.

This blind confidence in the cost estimating capabilities of RAM was only justified by his level of comfort with it rather than having an objective sense of control or understanding of the estimating process itself or of its logic. He was not sure of Revit's estimating capabilities and showed interest in exploring it, but that did not necessarily imply full knowledge of the underlying estimating mechanisms of RAM, but rather just a trust and comfort level towards his domain-specific tool:

S1*: I'll just go through and sum those three components from RAM and divide it over the 80000 square feet – and I've got it down to about 8.5 pounds a square foot now and then I usually throw a 10 percent factor on to it at this early stage just in case there are some changes – so I told (A2) to allow 9.5 pounds a square foot for the structural steel in this last release – and the estimator said he was calculating 9.5 pounds a square foot and he was adding 10 percent as well so there is a pound difference between us somehow – I'm getting 8.5 and he's getting 9.5.*

A lot of question marks start emerging when one looks at these discrepancies between (S1) and (C2)'s estimates for the same exact project, especially when the difference amounts to 1 pound per square foot. More questions are even raised when phrases like "*got it down to about 8.5 pounds a square foot*", "*usually throw a 10 percent factor on to it*" and "*there is a pound difference between us somehow*" come into play. Are both teams aware of the underlying logic of the estimates of each other? What is the mechanism of getting the cost *down* to "X" or "Y" tonnage? Whose estimate is more accurate then? Is the lower tonnage any better or any *safer* to take into consideration, or is the conservative estimate really too much and should be revised? (C2)'s feedback raised even more doubts:

C2*: He [S1] informed (A2) that he felt like we were conservative – so what we did was we went back and analyzed all of our steel and all of our formulas and we cut our waste from 10 percent to 5 percent because there were a lot of long columns and the longer your columns are the less factor your base plates have to add – so we looked at it and decided to cut the waste factor for base plates and cap plates and things like that from 10 percent to 5 percent – and it did not get down to his number.*

What is the basis of reconciliation between the two teams? Why is "*cutting the waste factor*" the best solution to reach common terms? What is the decision making mechanism here? Is it the only factor or is there another hidden rationale behind the discrepancies? Obviously (C2) did not "*get down to his number*" and so there remains more ambiguity in the whole calibration and reconciliation process. He realizes that "*his [S1] tonnage is run off of his computer program*" but he would still "*love to get that information…love to look at it*" to make some informed decisions. Although he has a best guess as to where the cause of the discrepancies is, which is miscellaneous steel, he states he is willing to "*use his [S1] number*" but is still persistent at the same time and confiding in his own calculations:

C2*: Our number was in budget so what I told (A2) was if you don't mind I'm staying with my number – I will use his number if you want me to but I just don't agree with it – and I'll tell you where I think it is – it's in miscellaneous steel that has not been defined yet on the drawings because he still designs so he can't pick up every little piece of steel until he's complete with the design.*

Although (C2) seemed more conservative in general in his estimate, he could explain the logic behind his decisions. For him, it was not just "*summing three packages*" out of the RAM cost analysis results "*which you have to do manually*" as was the case with (S1), or a "*three minute exercise to just go through and cut off the numbers*" from the automated RAM estimate. (C2) explicitly drew the logic behind his estimates in every design phase:

C2*: Normally at SD we'll do the 8 or 9 pounds per square foot that structural engineers like then I put in one pound of miscellaneous steel to the whole building – that's miscellaneous beams and miscellaneous stuff that is not in your structure but it's a lentil over a wide door – it's backup to curtain wall that is too tall and you got to put a tube behind it…it can be elevator ladders or roof ladders – it's miscellaneous.*

The one pound of miscellaneous steel seems like an indefinite assumption, but is actually informed by information from the architectural drawings that (C2) assumes (S1) did not look into closely. So even at schematic design, (C2) used information from both the structural and architectural representations to produce his estimate. (S1) however relied mostly on the RAM estimate that uses the conceptual structural model as its basis and ignores miscellaneous steel that is implicitly embedded in the architectural model at this early stage of design:

C2: *Because some of the steel – it's structural steel but it actually comes off the architectural drawings – because it's lentils – the structural engineer just has a schedule – an opening is 10 foot wide – it doesn't show up on his drawings – you got to go to the elevations and say we've got 14 windows out here that are 20 feet long – 14 windows with a 20 foot beam – and that's where it comes from.*

As the design gets more and more elaborate, (C2) works on reducing his assumptions but still being informed by the quantities of steel in the latest architectural and structural models:

C2: *Some of that miscellaneous stuff is designed in and we actually see it so we'll reduce it to maybe a half a pound per square foot – and then at CD when we got everything on the drawings we get all the architectural drawings and all the structural drawings…I hope at CDs he's right but I know I'm covered either way.*

There still remains a subjective component in each of the approaches; one that is mostly influenced by expertise and tending towards a more conservative approach to acquire a sense of being "*covered*" in terms of liability as with (C2), and another that tends to go for the "*efficient design*" to satisfy the client as with (S1):

C2: *So many unknowns – we were close enough that I didn't see there is a big variance…I think the reason he was concerned is…most structures we can get out for like 8 pounds per square foot – this one was running 8.7 or 8.8 and that probably was because that's a factor that I'm sure that he looks at as a structural engineer because he wants to give his client the most efficient design…and let's just say he thinks it's supposed to be 9 and his design pops up 12 he's going to be doing the same thing I'm doing if my cost pops up 40 when I know it should be 30 – he's going to be in there looking for where did we plug something in the computer.*

Another difference between (S1) and (C2)'s approaches in general was this dilemma between professional expertise and reliance on analysis results coming out of domain-specific software. While (S1) was confident and more comfortable with the tool and consequently in its results, he had less control over the estimation process itself and how it was generated. In addition, he was more occupied in the "*structural view*" of the model imposed on him by the structural analysis tool, focusing on weights and loads and ignoring some of the architectural elements and their impact on structural cost. (C2) however followed a more holistic approach and studied models of all the consultants carefully to formulate an estimate that takes into consideration all factors and elements from an early point in the design process, and make his assumptions that are embedded in the estimate based on informed decisions. His confidence in his professional experience and background in estimating was more dominant than his confidence in cost estimating software packages. He refused to rely mostly on the tool to inform his decisions, as he would have then no method to track the logic of his procedures. (C1) introduces another factor to the scene, where he relates the conservative approach of (C2) to the general attitude of outside consultants, where the process is less "*seamless*" and they are more "*nervous*" and "*uncomfortable*" about "*filling in the gaps*" than in house consultants:

C1: *They [outside consultants] are just a little bit more nervous when they don't see certain things or see things in a certain way whereas I guess in house we're just sort of used to…the further away you get from doing it in house the more questions because people are more nervous or more uncomfortable with the information they've got and filling in gaps and all that – and obviously contractors are too because they've got more at risk than the rest of us do.*

The fact that the process is more "*formal*" and that the consultants are "*more at risk*" the further away it is physically from the architectural firm introduces in (C1)'s point of view more tendency to be more cautious, conservative and "*ask more questions*":

C1: *And these guys (C2) and them they ask a fair amount of questions and maybe I ask that many too I just don't realize it because it's something as easy as walking past there and saying hey what about this so it's not very formalized when it's inside – when you go out of house then it gets more formal.*

If it was up to him to conduct the estimate at this stage instead of (C2), (C1) suggests he would have been more "aggressive" in terms of pricing and more free to specify the cost figures explicitly with no fear of being "*low on the numbers*" as most outside consultants tend to worry about. Being too conservative may make the numbers in the estimate "*get out of hand*" if not calibrated properly:

C1: *I'm not a firm that has a reputation to worry about – here I can kind of go straight at the number with a certain amount of contingency and just let the number be what it is – whereas I sense or I have always felt like the minute we go out of house some of those cost consultants are trying to protect their reputation – and what they don't want to be is low – especially back in the days when we used to bid – they don't want to be the low bidders so they tend to sort of build contingency in and you just got to be careful in doing that because it can get out of hand.*

Figure 5.9 shows how (S1), (C1) and (C2) approached the cost estimation process, all starting from the BIM base model. As shown in the figure, although the starting point is identical, the estimates resulting from each approach can never be the same and have to be reconciled among the estimators.

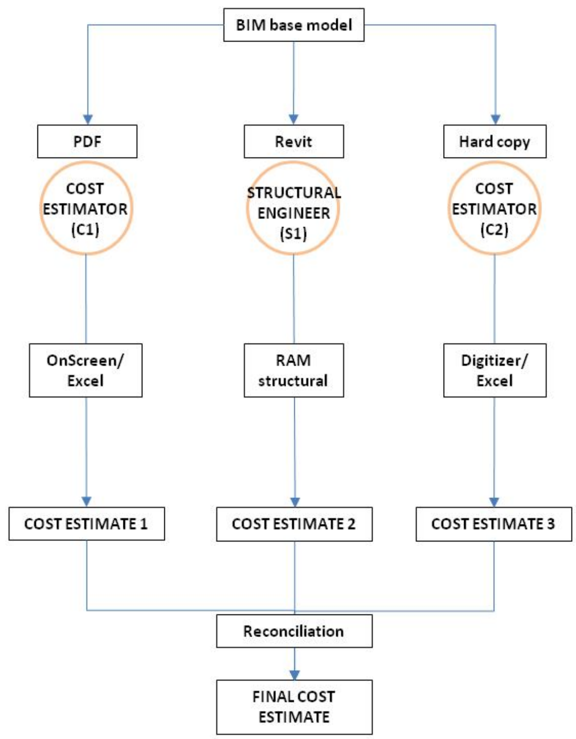

Figure 5.9. The cost estimation approach by (C1), (S1) and (C2) starting with the same BIM base model

Another concern that both (C1) and (B1) shared was that less reliance on the software to produce a "*good take off*" could result in inaccurate estimates due to "*scope differences*" rather than unit cost differences. Many factors come into play in events of this sort. The deviation in workflow, tool and process was significant, where estimation was performed by (C1) then (C2), with different approaches and tools. The discrepancies that took place between the results of the estimator and the structural consultant showed the emergence of some factors including the difference in approach, expertise, tool proficiency, and the subjective component in both mechanism and reconciliation process.

5.4 Discussion

Chapter 4 introduced personas as the basic theoretical unit of inquiry and analysis in the dissertation study and demonstrated how multi-membership of different communities of practice for individual participants shapes their approaches and understanding of BIM. Chapter 5 presented some of the most prominent types of interaction among disciplinary participants that were identified in the study and are highly relevant to the basic inquiry of the research. Specific events were discussed that focus on salient issues in each type of interaction. The question remains: what does all this mean for communication of design intent among disciplinary teams and participants in BIM-enabled practice, as per the research questions and goals? From the previous description, it was shown that the socio-cognitive component of this communication, comprising affordances and limitations with respect to both tool and social interaction, takes place at multiple levels: (1) non-disciplinary communication, as with architect-client interaction; (2) intradisciplinary communication, as with the interaction within teams; and (3) interdisciplinary communication, as with the interaction with in-house consultants and with other AEC teams. According to the conceptual categories identified in the coding and analysis process, different components come into play in each level of communication with varying relative weights. The role of BIM representations as well as other forms of representation and communication is by and large distinct in each case, or more precisely at the "*interface*" between different participants and teams.

In non-disciplinary interaction, issues related to interpretation emerged as salient to architect-client interaction, which was characterized by ambiguity of the client's needs and the continuous process of interpretation of requirements by different team members. Status and system of authority, in addition to the ambiguity of client requirements and the need for multiple and alternative interpretations were dominant components of the interaction. At the *interface* between the architectural team and the client, interpretation of requirements through verbal communication and imagery was predominant. As was shown in event 1, there was a lot of effort done by the architectural team just trying to read through what the client meant. The images he presented to the team were primarily the means of conveying the desired massing and look of the building. The team had to go through a process of careful reading into those images and extract exactly what elements he wanted to emphasize. Not only were multiple participants being involved in this *reading* process, but also they were members of different communities, and so their interpretations were shaped by their multi-memberships. (A1) was more focused on reading through the desired percentages of materials and glass in order to apply that in his parametric design of the external façade. This was more or less a translation of material percentages captured from the images to input parameters for areas of different materials in the BIM model. (A4) was more interested in her reading of the images in the conceptual and philosophical approach to the design of the building and exploring what different alternatives of façade composition meant for the building character and for the functions inside the building. This allowed her to make more exploratory sketches than making clear cut decisions of how the building *should* look like. (P1) was more interested in the holistic approach of designing the building in terms of its significance as an icon that represents the image of a technical college and reflects the specialties of the firm and its approach to treating this prototype of buildings in future projects.

At the same time, the architectural team did not have to submit BIM models to the client in any of the design phases. Following the reading and interpretation of the client's requirements in early schematic design, the team had to translate their understanding and their approach into a language the client could easily comprehend. They presented 3D renderings of their early concepts in addition to images of precedent projects done in the firm or elsewhere in attempt to capture the client's needs and narrow down alternatives for further development. In later phases of the design, deliverables were always in the form of print outs of 2D drawings and not the BIM model. The approaches taken by both the client and the team were effective to some extent in acquiring the client's taste and conversely in getting feedback about progress in the project. The fact however that the BIM base model was not an essential component at this interface played a role in the missed opportunities that could have allowed for a better understanding.

In intradisciplinary interaction, issues related to conceptualization and reflection emerged as salient to the interaction among members of the architectural team. As the discussions with the client were propagated through the architectural team, cognitive overload and conceptualization constraints began to emerge at the *interface* between the team members while attempting to use the BIM base model as a shared thinking space. More representations and methods of communication came into play, including verbal communication, sketches, physical models, rendered images, and digital models. Although the collective expertise of team members, coming from different backgrounds and having different skill sets, was helpful in getting the job done, conflicting positions within the team regarding personal preferences of tools and workflows, added to peer pressure and status, contributed to a state of disconnect among the team members. As shown in events 2 and 3, the medium of representation among the architectural team members was mostly either sketches or print outs of the BIM model, and so the communication was less open to interpretation than with the client. There was still some miscommunication however and issues with conceptualization owing to the multi-membership of the team members. Although sketches were more ambiguous than the model representations, they allowed for more collective reflection and thinking. Model representations were constraining for (A4) and (P1), as they did not allow them to experience the top-down approach or normative approach they were used to during a schematic design phase. (A1) however used them strategically for design thinking. He was able to employ the parametric relations, massing operations and the "design options" functionality in the BIM tool from day 1 to develop the design and respond quickly and efficiently to any changes from the client or any emerging requirements. These functionalities were more suitable for his bottom-up approach which involved stacking spaces and establishing parametric relations to extract and track information seamlessly and to perform the necessary design modifications.

The fact that there were still multiple readings of the model in this type of interaction affected the nature of communication of design intent. First of all, the model was not the sole artifact or shared representation that the architectural team used throughout their thinking and design development process. Their thinking process was distributed across a number of representations. According to (A4), this was how it should be, and designers should not be constrained and forced to use the one and only tool. However, with discrepancies in the *membership* of each of the team members, each used his or her preferred method and means of representation to express their design ideas. This led to a complex web of multiple *reading* and multiple *writing* activities. Each team member acquired not only a different reading of the design than the other member, but also a number of readings from different sources and representations. On the other hand, each team member *wrote to*, or contributed to, the model directly or indirectly in different ways. (A4) used sketching most of the time but attempted to model in Revit during design development. (A1) often used a combination of modeling and sketching to express his ideas. (P1) only sketched to the rest of the team and relied on their ability to translate his drawings and diagrams into the model. With this continuous process of varying reading and writing approaches, there was much potential for misinterpreted information, or miscommunication of ideas among the team members. The fact that the reading and writing activities were distributed widely among different representations and not just the BIM model not only demoted its significance as a shared thinking space, but also implied that the model as an artifact represented only partially the activities and ideas expressed in design meetings and brainstorming sessions.

Events 4 and 5 present two other examples of writing and reading of the BIM base model in intradisciplinary interaction. Event 4 shows another aspect of *writing to* the model and the partial representation of information, which is the level of detail of model*ing*. As the team members indicated, the scope or level of detail of modeling relies primarily on the method of delivery of the model, where a 3D model deliverable implies a *full* representation of model elements, while any other form of representation implies a model that just *looks good* and does not necessarily communicate a full-fledged 3D model. Although a full representation of each and every single model elements was not originally a goal, (A1) saw opportunities in representing and overlaying some elements such as equipment and furniture for the internal purpose within the team of coordinating elements spatially. This was seen by (A3) as an unnecessary process. She highlighted the importance of defining beforehand the purpose of the model; if it was to be used for the accurate extraction of information or if it was just a model for internal studying and coordination purposes. As this process of writing to the model in *intra*disciplinary interaction represents a kernel of the information exchange process with other AEC consultants, any partial representation of information would definitely have an impact on *inter*disciplinary interaction and lead to more interpretation setbacks.

Event 5 introduces an example of an affordance of BIM related to collaboration within the architectural team. By navigating through the BIM model collectively, each team member was able to read through the model and subsequently many of the design aspects at a high level of detail. Again, as the team members came from different communities of practice and engaged collectively in another, their process of reflection and conceptualization was augmented through the sense of immersion in the virtual model. With 3D navigation, there was less ambiguity, and more opportunities for reflection and thinking about details of the design. In other words, there was more potential for a closer *reading of* the design aspects and less *reading into* them. Is it right to assume then along the spectrum of means of communication (which comprised verbal communication, imagery, sketches, BIM model representations, and BIM model navigation), that there was definitely more *reading of* and less *reading into* the design for all team members at the BIM model neighborhood of the spectrum and vice versa? That was not necessarily the case. (A4) had a better reading of the design with sketches and with 3D navigation, but not with the model representations. They introduced a constraint and required a level of interpretation and reading into the dull lines of the model to understand what they could mean for the design. Images were also constraining as they forced the team to use specific motifs in early exploratory design phases. (A1) had a better reading of the design with BIM model representations and navigation, as well as imagery. These all represented tangible references that he could use to map to his design approach, rather than having to read into sketches and verbal instructions.

In interdisciplinary interaction, which involved interaction with both in-house and external consultants, issues related to recognition of the needs of other disciplinary participants and managing the shared space of communication enabled by the BIM base model emerged as salient. In this type of interaction, the BIM model was at the core of the *interface* between the architectural team and consultants, and it was beneficial as a shared repository in terms of coordination of information. Heated arguments across teams in several cases and events pointed out the need to supplement model exchange with other forms of representation and communication, as merely updating the base model was not sufficient in carrying the necessary data or conveying the intent of the designer to other disciplinary participants and vice versa. Technical issues related to incompatibility among tools also contributed to *missing* or *lost* data during the exchange of models.

Events 6 and 7 introduce interesting examples of reading and writing to the model. In the architectural team's interaction with (C1), there were missed opportunities in extracting useful information from the model. There was a big difference between how

(A4) and (A1) communicated the design information to (C1), which was only *writing to* the model, and how he expected it to be communicated, which was to *write for* him. Writing to the model did not necessarily guarantee an understanding of the needs of (C1) and what kind of information must be included in the model. As both (A1) and (A4) did not belong to the estimating *community*, cost for them was only an afterthought. They did not embed all the necessary information in the model for the purpose of estimating, and expected (C1) to use the available information accordingly. In (A4)'s case, her inexperience with modeling was another factor, as she worked most of the time with sketching to develop the design idea for the outdoor bench and represented it in the model only as a rectangle without considering the ramifications concerning cost and other issues. (C1) had to not only read into the model information to understand its relevance to his analysis process but also write to that information by making assumptions about building model elements and input parameters. This however was mostly done as a discrete approach without engaging the team and therefore led to more ambiguity. (C1) did not always get the appropriate level of detail required for his analysis, while (A1) and (A4) continued to exchange models without the necessary information, and at the same time did not get feedback from (C1) except at distinct project phases.

As this endless loop of misreading and partial writing continued, (B1) intervened to reconcile the tensions between the two parties. As shown in event 8, the primary role of (B1) was to enable the architectural team to *write for* the estimator rather than just *write* some irrelevant data *to* the model, and therefore reduce the burden on (C1) to *read into* the model information and on (A4) and (A1) to *read into* (C1)'s requirements, and enable both parties to acquire a better *reading of* the design and cost analysis feedback loop efficiently. Being a member of neither community but aware of the needs and responsibilities of both, and as a BIM manager who was aware of the technical approach required, (B1) was able to understand the requirements and concerns of both parties and bridge the gap between their perspectives. He realized that in order to *write for* (C1) and reduce the amount of *reading into* the model information, (A1) and (A4) had to be informed explicitly of the input parameters that they had to provide for the estimation process, and so worked with (C1) to identify the requirements in detail. At the same time, to enable a better *reading of* both the design and cost analysis, (B1) introduced Innovaya Visual Estimating and Timberline to achieve a more accurate interpretation of the BIM model data and generate results that would be easy to *read* by the architectural team.

Event 9 introduces an example of interdisciplinary interaction with AEC consultants that involves pragmatic workarounds developed by (A1) to facilitate the model coordination process. Instead of extensively *writing to* the BIM shared model, both (A1) and (M2) decided to develop a workaround that allows them to *write for* each other's needs regarding lighting fixtures. (A1) was not only a *member* of the expert BIM user community, but also his previous experience in collaborating with AEC consultants and experimenting with different coordination methods allowed him to develop an efficient strategy from his viewpoint. Rather than using the model ownership functionality as is, where each party had to *read into* the ownership of model elements, (A1) suggested that the architectural and MEP teams each input their corresponding light fixtures in the shared model space and track their location and adaptability separately, allowing for a better *reading of* those fixtures for coordination purposes. Again, the issue of level of detail of modeling appears as salient in this event. As the participants exchanged models, they tried to take into account the sufficient level of modeling detail for other disciplinary participants. This presented another level of *writing for* participants and teams rather than just *writing to* the model without considering their needs.

Event 10 presents another example of interdisciplinary interaction with AEC consultants that addresses the potential misinterpretation of information among participants during coordination and conflict resolution phases. Both (A1) and (S2) *wrote to* the model but required additional channels of communication to ensure the validity of the exchanged information. (A1)'s previous experience in collaborating with other consultants and his expertise with modeling tools and clash detection tools allowed him to compare and use the most efficient method of coordination and conflict resolution from his perspective. However, the methods used were not sufficient for a full *reading of* the communicated design information. (S2) for instance had to read into the updated models and figure out whether the model elements were intentionally modified or relocated by (A1), or if that was just a modeling error. Event 11 showed how the same building model can induce different *readings* by different participants. Not only were there discrepancies in the cost analysis results between (C2), (S1) and (C1) due to the diversity in methods they used to extract cost related information (digitized drawings, structural analysis estimates using Revit and RAM, and OnScreen take off using PDFs), but also each had their own perspectives about the essential components to be integrated in the estimate. In other words, the discrepancies in estimates resulted from both the conceptual structure of the tool used by each and their own *reading into* the provided model information. They had different assumptions and input parameters based on their individual backgrounds and their viewpoints about what needs to be incorporated in an estimate at each stage of the design for accurate results.

To better understand the nature of communication of design intent as seen in the study observations, it is necessary to identify in depth what takes place at the *interfaces* of information exchange in the different types of interaction in terms of process, phase, workflow, affordances and limitations. These are discussed in Chapter 6, investigating into the *gap* between data exchange mechanisms in BIM as seen in hypothetical models of collaboration and shared project information, and the argumentative process between different participants in practice as per the research inquiry and the observation results.

CHAPTER 6

REEXAMINING THE SHARED BUILDING MODEL

This chapter introduces a rereading of the BIM model as a shared space of interaction as per the dissertation study. By dissecting hypothetical models of shared project information, instantaneous workflow and synchronous collaboration offered by BIM, communication patterns are introduced based on a pragmatic reading of interdisciplinary, intradisciplinary and non-disciplinary interactions enacted in practice. According to this reexamination, a description is provided for different states of the shared model, discussing the conditions representing the nature of situated interactions of participants with tools and with each other. This is followed by a discussion of the characteristics of the shared model as a boundary object that is interpreted differently across multiple communities of practice but carries content that is recognizable to all those communities, where the activities of participants and the nature of the boundary object both affect the communication of design intent among participants.

6.1 Introduction

From the analysis and coding, *In Principle versus In Practice* appeared to be the most salient in terms of emergent coding categories. At large, it includes subcategories related to the expectations of BIM with respect to workflow efficiency, coordination and phase of engagement in the process. It also goes beyond those identified subcategories to encompass and describe components in many other categories. Categories that highlight problems associated with BIM tools such as *Cost of Tool for Teams* illustrate the high expectations of disciplinary teams regarding for example coordination versus issues that those teams encountered throughout the process including coordination and management overload. Even the category *Affordances with Respect to Collaboration* cannot be described solely in terms of gains, but has to be seen through the lens of both a hypothetical view and a pragmatic view. Conflict detection and resolution for example has to be seen both in terms of what the tool capability offers versus how it is employed in practice and enacted by participants and teams in their interaction.

The study described in the dissertation research highlights one context of interaction in BIM-enabled practice, which may have portrayed in detail some aspects of design intent communication but does not necessarily claim to have covered all aspects for all contexts. In order to understand these contexts, it is necessary to address the relationship between the results and findings of the context of study in this research and how applicable they are to the larger pool of cases of AEC disciplinary teams, in a process known as transferability (Lincoln and Guba, 1995), as described earlier in Chapter 3. In fact, the dimensions of this pool of cases are believed to lie along a spectrum that ranges, as mentioned above, from the hypothetical (as described by software vendors or in idealized business models) to the pragmatic (enacted in practice). By laying out the assumptions that were central to the identified categories in the dissertation research study, a basis for comparison can be established along this spectrum for the characteristics of the study and other related contexts.

Section 6.2 of this chapter explores the hypothetical view of what BIM offers in the AEC industry as portrayed by existing business models proposed by AEC software developers and other sources in the literature. Points of interest include workflow and communication efficiency, accuracy of exchanged data, shared repository of information, the impact on the profession and on changing roles of participants, as per their relation to the main research inquiry in the dissertation. Section 6.3 then examines these topics in light of the dissertation study and the key findings of the observation. This is done by looking closely at the *interfaces* between teams and participants in the study and unpacking them in terms of their actors, representations, and patterns of interaction and information exchange.

By observing what *actually* took place at those interfaces in practice and over time, patterns of interaction towards the pragmatic end of the spectrum can be described. These patterns, being within a larger context of disciplinary interaction, do not represent just detached interfaces of data exchange, but are shown to represent different states of the BIM base model. These will be discussed in section 6.4.

6.2 The Shared Project Model

The transition to BIM in the AEC industry is inevitable. According to McGraw Hill (2009) market report surveys, about 50% of the industry, including contractors, is using BIM or BIM-related tools, with a 75% increase in usage over two years. Recording about triple the percentage in 2007, the number of expert users has increased to 42% of BIM users, 67% of which use BIM on more than 60% of their projects. Even non-users of BIM were reported to being open to exploring the potential value of BIM, 42% of whom believed that BIM will be highly important to the industry in the following five years. Most BIM users see positive Return on Investment (ROI) for BIM in AEC projects, including 63% of users and 70% of owners. 93% of BIM users believe that there will be more potential to gain more value from BIM in the future.

According to Gonchar (2007), productivity gains in documentation preparation and client demands for enhanced quality services are the two basic drivers for BIM growth, wide adoption and gaining competitive advantage in the marketplace. More advantage is gained in essence if the time, effort and money spent to meet owner requirements and generate reliable and correct documentation are reduced. With more and more pressure from clients, AEC designers and engineers are widening their services to include BIM-based performance analysis, cost estimates and scheduling, value engineering, and facility management and operations analysis, rather than rule of thumb judgments and experience-based heuristics (Eastman et al., 2008).

The premise in the dissertation research is that the gains associated with these two basic drivers are directly related to effective communication of design intent among all AEC participants. Meeting the owner requirements through enhanced quality services entails that design information is communicated and coordinated correctly, consistently, completely and smoothly to and from the owner, and consequently among architects, engineers, consultants and contractors working on the project. Preparing reliable and correct documentation requires efficiency in the automatic extraction and exchange of data among software applications and participants and reducing errors, omissions, and requests for information (RFIs).

Many BIM software vendors have approached these two drivers in their solutions by promoting the notion of the shared project model or shared building model repository. By working on a single shared model, architects, designers, engineers, contractors and other AEC participants are believed to coordinate and work on various design issues in a much more efficient way than traditional interdisciplinary channels of communication. As shown in figure 6.1 and according to buildingSMART (2011), traditional communication channels imply information chaos, while the shared project model enabled by BIM implies smooth flow of information across all participants, where the shared repository of information enables instantaneous and synchronous workflows in the collaboration process and a more efficient coordination of design information.

However, as the dissertation study indicates, this shared project model cannot comprise all the interdisciplinary, intradisciplinary and non-disciplinary interactions that take place in a given project, and therefore cannot possibly provide a fully efficient communication and coordination process. By dissecting the shared project model and looking closely at the types of interaction taking place at the mutual interfaces between all participants throughout the progress of the project, the model can be reexamined and revisited as a shared space of communication that has specific affordances and limitations; the ultimate goal being laying the ground work for higher rates of adopting

BIM based on projected smooth workflows, enhanced productivity, and reliable and credible exchange of information among participants.

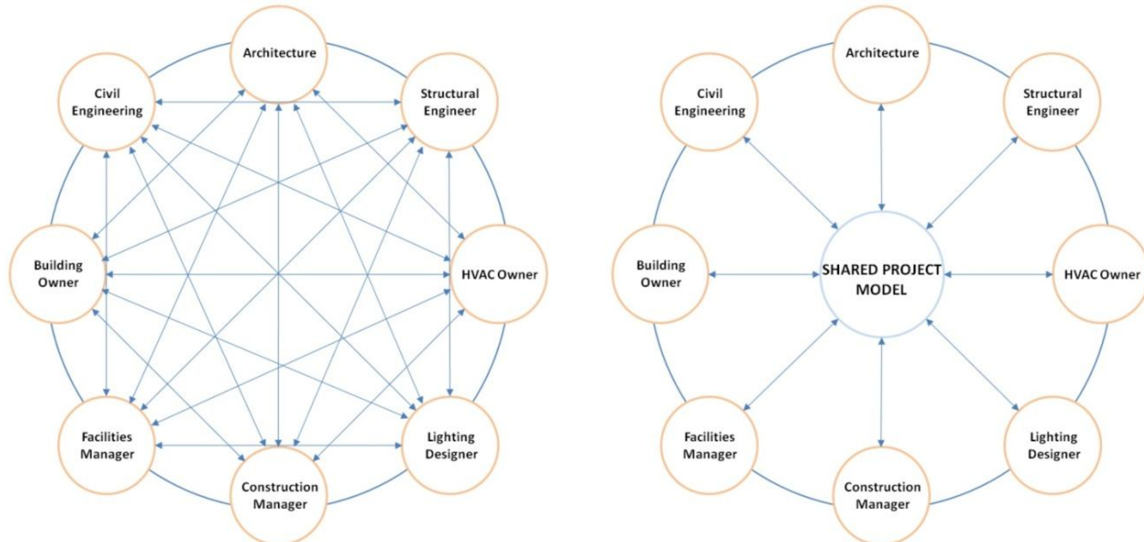

Figure 6.1. Effect of BIM on communication among AEC participants, Left: Information chaos, Right: Shared project model (after buildingSMART, 2011)

Section 6.3 examines the shared project model based on the personas and observed interactions in the dissertation study, where segments of interaction between specific participants using the shared building model repository in the SG project are extracted and explored across the different design phases.

6.3 Interfaces of Information Exchange

Based on the personas and types of interaction discussed in chapters 4 and 5 for the SG project, this section presents a detailed description of the interfaces in each type of interaction; interdisciplinary, intradisciplinary and non-disciplinary interaction. Each interface shows the main participants involved, the communication channels and patterns employed in the project, in addition to the digital and non-digital tools and representations used in the interaction process. These are described for each of the three phases observed in the project; schematic design (SD), design development (DD), and construction documents (CD). The goal in introducing these interfaces is not necessarily exhausting all the personas and possible types of interaction, but providing representative examples that encompass the most salient communication patterns. Figure 6.2 shows the main interfaces examined in the SG project. Interfaces (1 to 4) describe patterns of communication observed in interdisciplinary interaction. Interfaces (5 to 8) describe patterns of communication observed in intradisciplinary interaction. Interface (9) describes patterns of communication observed in non-disciplinary interaction. These are illustrated in the next subsections. Interfaces are labeled by the dominant tools and representations used in the specific type of interaction. For example, interface (3) describes a pattern of communication where the main tools involved are BIM-authoring tools and CAD modeling tools.

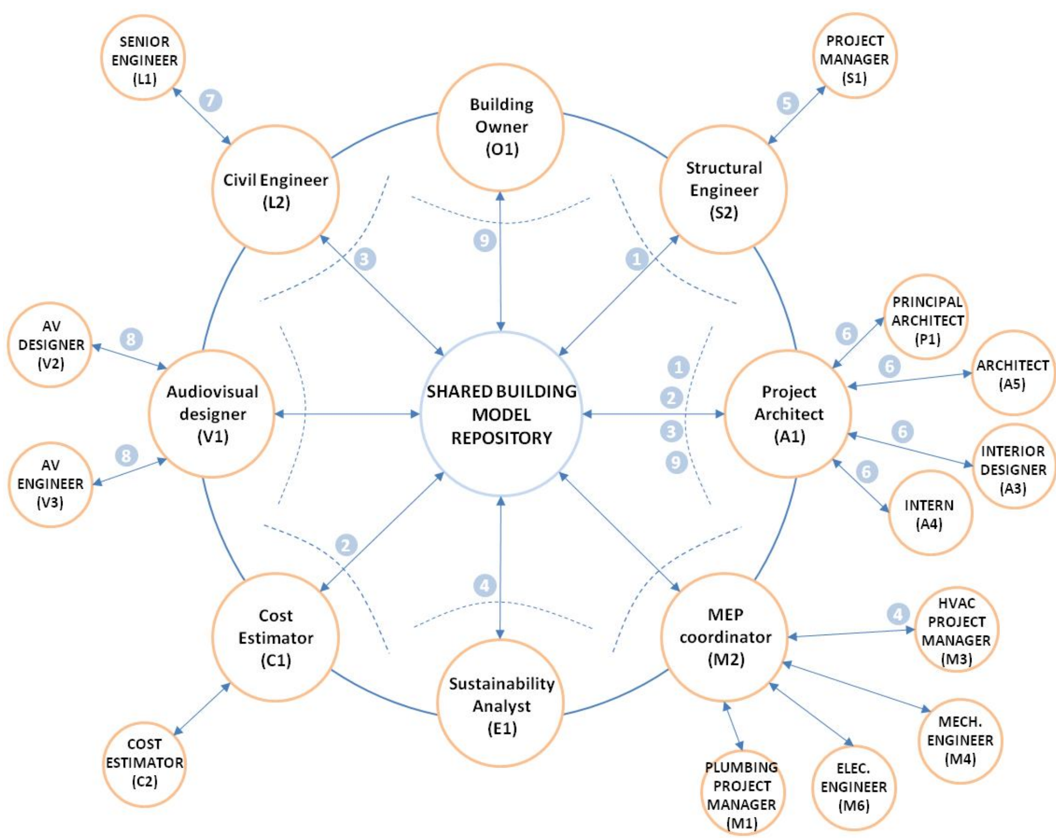

Figure 6.2. Examined interfaces at the shared building model repository space in the SG project

6.3.1 Interfaces in Interdisciplinary Interaction

6.3.1.1 Two BIM-authoring Tools

As an example of this pattern of interdisciplinary interaction, the interface between key participants in the architectural team and the structural team is examined (interface 1). The main tools used at this interface were BIM-authoring tools (in this case Autodesk Revit Architecture for the architectural team and Autodesk Revit Structure for the structural team). The tools and key participants at this interface however were not consistent throughout the phases of the SG project. In the schematic phase of the project, as shown in figure 6.3, (A1) was continuously updating the BIM base model using Revit Architecture but preferred not to exchange the model with all the consultants, including structural, until it was mature enough. He believed that it was too early to exchange the model at this stage, and that it was mostly needed for coordination purposes, which would make more sense in subsequent phases.

Figure 6.3. Interface1 (ARCH-STR) in the SD phase of the SG project

(A1) extracted DWG files out of the BIM base model and shared those files and other drawings in the form of PDF files via the project online server. In project meetings, (A1) shared PPT and PDF presentations, and often opened the BIM base model to prepare the different teams for the next phases in terms of coordination and conflict resolution. (S1) was the primary contact and participant at this stage for the structural team. Although working in RAM Structural Systems to perform the necessary structural analysis, the output from (S1) was basic 2D drawings in DWG and a narrative for the preliminary structural systems for the project in PDF form.

In the design development phase, as shown in figure 6.4, the structural team started to use Revit Structure for modeling based on (A1)'s updates via the project server. As (S2) was more knowledgeable in using the tool, he became the primary contact for (A1) in this phase in terms of modeling and detailing, while (S1) communicated more with (A2) regarding higher level decision making in the project. In project meetings, which mainly involved the participation of (A1), (A2), (S1) and (S2), the discussion was usually over hard copy drawings and not directly over the BIM base model. There was an agreement among both teams that the process of redlining and taking notes over hard copy drawings was more practical and sufficient for this phase. More verbal communication and physical meetings were necessary at this phase to ensure both teams were on track and understood each other's needs.

At the end of DD, (A1) occasionally used PDFs for online communication with (S2). He extracted building sections from the BIM base model, marked them up digitally on the PDF file, and then sent them to (S2) in order to have a digital copy and a visual sense of the updates. He also kept one master printed out copy for himself to make personal notes. At the end of the week and sometimes through the weekend, he would spend a couple of days reviewing all the updated structural engineering drawings received via the project server. After that, in addition to his personal notes on the printouts, he would create a PDF file with all his comments so that he could distribute them to the structural team and other consultants.

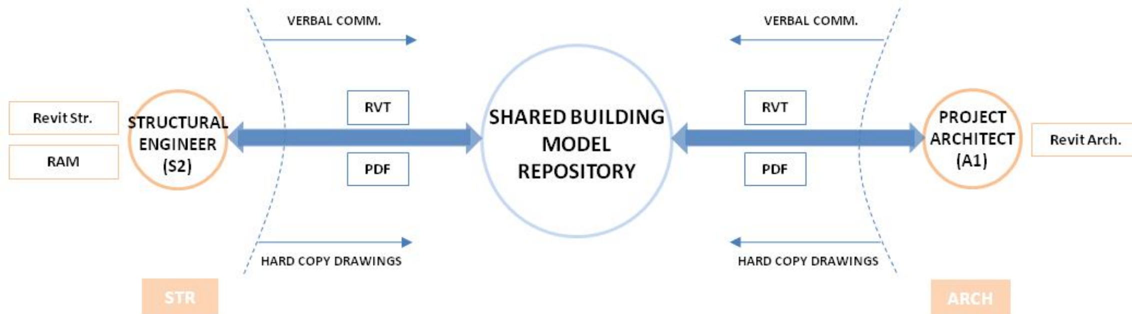

Figure 6.4. Interface1 (ARCH-STR) in the DD phase of the SG project

In the construction documents phase, as shown in figure 6.5, (A1) and (S2) still continued to use the Autodesk Revit platform, but more for coordination and conflict resolution. (A1) preferred not to use any conflict checking software like NavisWorks. He believed the BIM-authoring platform was sufficient for coordination purposes, and that conflict checking software would result in countless instances of errors and violations that would make it less practical time wise. (A1) used two main methods within Revit for coordination; the copy monitor functionality, and DWFs. (A1) and (S2) used the copy monitor functionality first to track changes and updates to the BIM base model. With the continuous updates and frequent adjustments, it became harder and less practical to continue using it, especially since it involved coordinating reflected ceiling plans with the structural system and MEP components such as ductwork and other equipment.

Communication through email and on the phone was central to this phase to verify any model updates by either team. In several cases, there were unintended modeling errors from (A1) in the server updates due to the highly frequent exchanges, especially close to submission deadlines. This forced (S2) to call or email (A1) to check whether the updates were carried out on purpose, and sometimes would even ask him for a separate update stating what exactly had been updated in the model to avoid any misunderstanding. After this communication took place, (A1) would still usually take a look at the printed out drawings to coordinate updates from all disciplines.

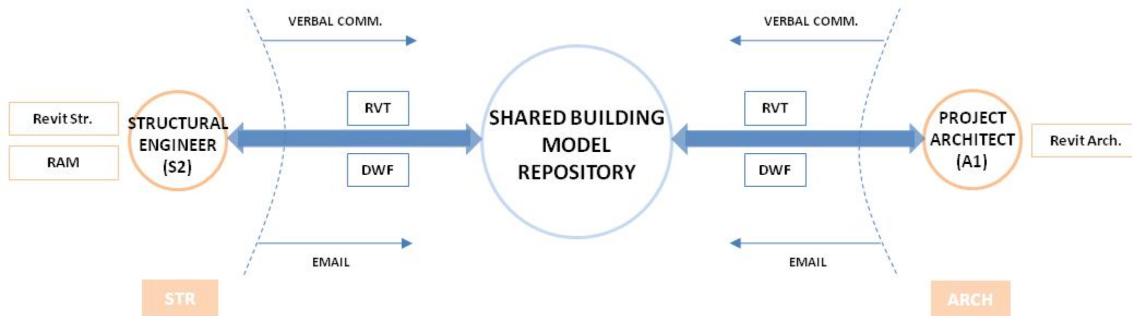

Figure 6.5. Interface1 (ARCH-STR) in the CD phase of the SG project

After having relatively little success with the copy monitor functionality, (A1) started using DWFs with the consultants near the end of the construction documents phase. He printed the whole set of drawings from Revit Architecture as a DWF, marked it up and sent it to all the consultants using the project server. (S2), for example, would import that set into the 'sheet view' in Revit Structure and pick up the redlining and markups. This method turned out to be more effective, as (A1)'s recommendations were explicitly embedded in the DWFs rather than (S2) having to go through the entire Revit file looking for updates and then having to check whether those reflected the full scope of what (A1) originally proposed. It also combined between the flexibility of redlining, as one would do on printed out drawings, and digital representation and updating in the BIM base model, where saving the model in Revit would automatically reflect any tasks that (S2) completed and updated in the DWF file.

6.3.1.2 BIM-authoring Tool and Cost Estimating Tool

As an example of this pattern of interdisciplinary interaction, the interface between the cost estimators and key participants in the architectural team is examined (interface 2). The use of Revit Architecture as the primary communication tool was consistent from the architectural team's side. Both the tools and participants at this interface were not consistent however throughout the phases of the project from the estimator's side. In the schematic phase of the project, as shown in figure 6.6, project architect (A1) continuously updated the BIM base model using Revit Architecture and generated PDFs for the in house cost estimator (C1), who was not a Revit user. (C1) used those PDF files to generate estimates using the OnScreen cost estimating software, in addition to MS Excel, where he had his own custom built spreadsheets based on precedent examples.

The estimate was done only near the end of the schematic phase, with very little communication, if any, between (A1) and (C1) in this phase. There were only a few discussions with (A2) about general goals and broad headlines, but there was no back and forth discussion about specifics in terms of affordability of certain materials based on the available and already tight budget. One of the consequences of this disconnect was an estimate that was 60% over the allotted budget. At the same time, (C1) had to make many assumptions about the building model elements, as there was very little information available to him from the architectural team who did not consider cost as an essential component in this phase.

This was a major issue at this stage, where the discrete paths followed in design and cost analysis feedback led to problems for both the estimator and the architectural team. Most of the architects in the team did not account for cost or did not know what (C1) needed exactly as information, and so he had to often revise all the model input parameters as some were missing, or not accurately modeled or communicated through the BIM base model. Sometimes he would even start over the process from scratch to obtain a reliable estimate. At the same time and as a consequence of being extremely over budget, a lot of rethinking of exterior façade materials and major redesign had to take place from the architectural team's side.

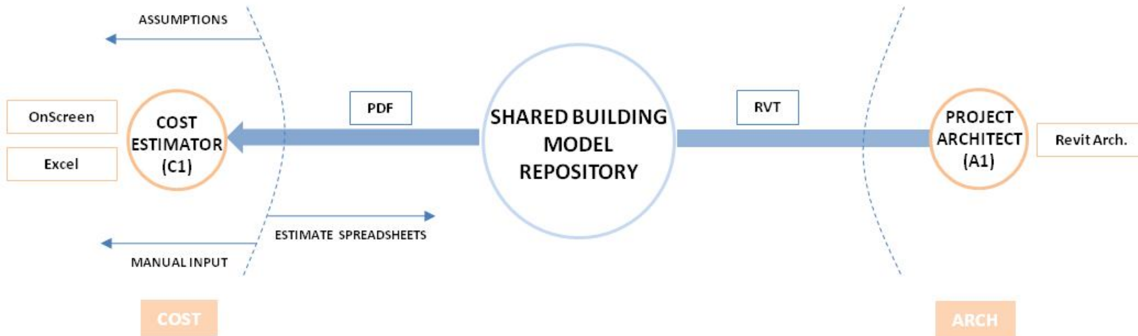

Figure 6.6. Interface2 (ARCH-COST) in the SD phase of the SG project

In the design development phase, as shown in figure 6.7, there was a key change in participants from the cost estimating side. (C1) was pulled off the project to assist with other tasks more important to the firm, and (C2) was hired as an external cost consultant and the primary contact to continue with the SG project. (C1) was occasionally involved as far as secondary assistance, as he had used (C2)'s team several times on other projects earlier. (C2) was even less tech savvy than (C1), and relied more on individual skill and domain expertise than on technology in generating estimates. His method of work involved mainly digitizing printed out drawings coming from the architect's BIM base model, working with the digitized drawings to extract quantities, and providing estimates using custom made MS Excel spreadsheets. As (C2) was an external consultant, there was more communication, on the phone, with both (A1) and (A2) for detailed inquiries about project specifics and the accuracy of his extraction method.

In addition to the architectural team, (C2) provided estimates for the structural and MEP teams. Except for structural, none of the teams double checked the results or had any other method of calibration. Two issues here come into play. First, there was built up confidence in (C2)'s results from both the architectural team and the MEP team, in addition to (C1), due to past experience. In spite of the very frequent BIM model updates that were different in pace compared to (C2)'s 2D method of extraction, both teams depended totally on (C2)'s expertise and his ability to generate reliable estimates.

Second, the structural team generated estimates for the same version of the building model at the same phase, but according to the calculations of the structural analysis tool. There were wide discrepancies in the results of both teams. Both (S1) and (C2) had their different perspectives and different reasoning behind their results, but (C2) was able to track his estimate and show how accounting for some items (in this case miscellaneous steel) was behind these discrepancies. There was no consensus however achieved between both teams to resolve this issue at this stage.

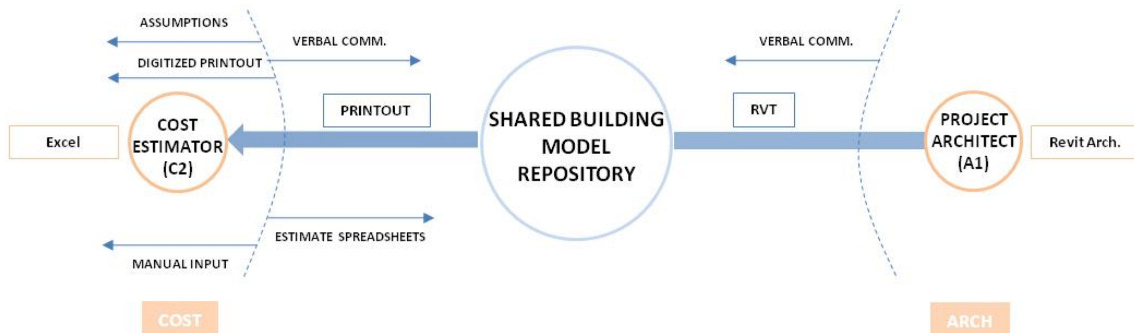

Figure 6.7. Interface2 (ARCH-COST) in the DD phase of the SG project

In the construction documents phase, as shown in figure 6.8, there was a desire within the architectural firm, led by the BIM manager (B1), to introduce cost estimating software that interface directly with Autodesk Revit and extract quantities more accurately. For (C1), this was a big step with a steep learning curve, but also a process that did not differ much in essence in terms of his task.

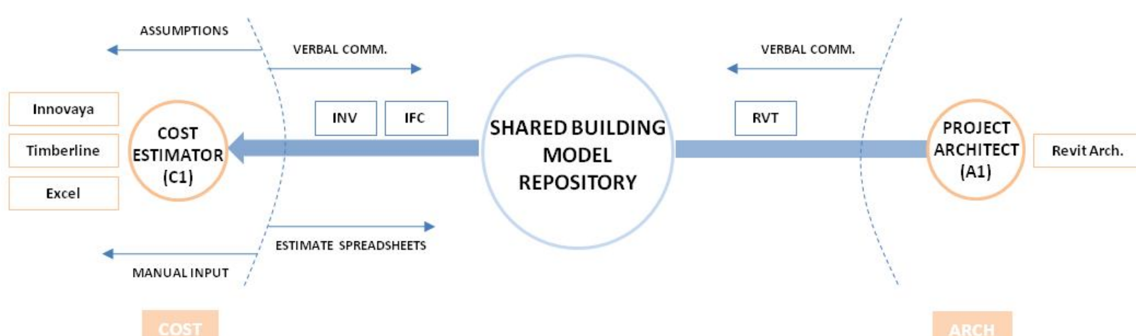

Figure 6.8. Interface2 (ARCH-COST) in the CD phase of the SG project

Although the process involved extraction of Revit schedules, and theoretically a seamless one, into Innovaya Visual Estimating software using INV format and then into Timberline using IFC format for estimating, those tools were no different than MS Excel in his mind. He would still have to go and check what the architects' input parameters were and make sure they conformed to the requirements for the line items in his estimate, regardless of the tool. This transition "to BIM" was work in progress at this stage, and the main estimating work was mostly carried out by (C2), with some input from (C1).

6.3.1.3 BIM-authoring Tool and CAD Modeling Tool

As an example of this pattern of interdisciplinary interaction, the interface between key participants in the architectural team and the civil and landscape team is examined (interface 3). The main tools used at this interface were BIM-authoring tools (Revit Architecture) for the architectural team and modeling tools (AutoCAD) for the civil team. The tools and key participants at this interface were not consistent throughout the project phases. In schematic design, as shown in figure 6.9, the senior engineer (L1) sent out site drawings in DWG format, and a narrative and other site utilities documents in PDF format to (A1) based on updates of the project site surveys and geotechnical reports. (A1) integrated the 2D site drawings into the base model and shared it with consultants. (L1) was the primary contact in this stage, as most of the tasks involved civil and utilities work on site. According to the contractual agreement at the beginning of the project, the civil and landscape team were to submit only 2D drawings in AutoCAD.

Figure 6.9. Interface3 (ARCH-CIVIL) in the SD phase of the SG project

In the design development phase, as shown in figure 6.10, more discussions about landscaping came into play especially half way through DD. (A1), (A4) and later (A5) were involved in these discussions with (L2). The group had several meetings to discuss planting, hardscape, and exterior features over freehand sketches, CAD drawings or PDF scans of sketches. Although (L2) worked primarily in Civil 3D and HydraFlow software packages, which contained 3D components related to terrain modeling and piping, the output was 2D AutoCAD drawings which ruled out any 3D aspects of the building site.

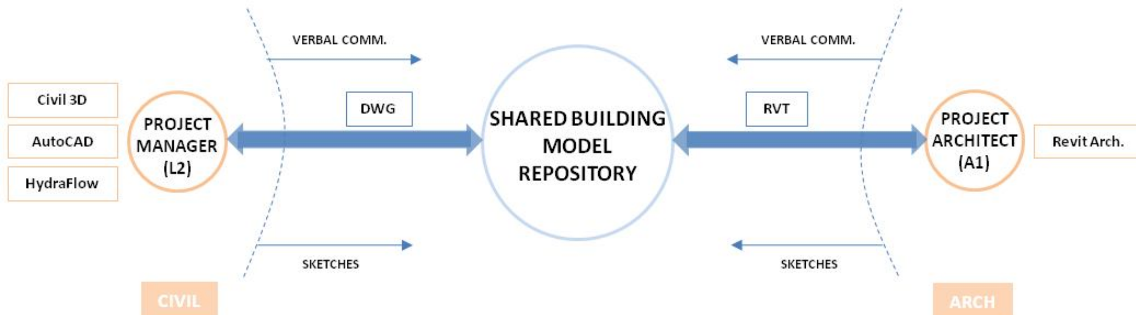

Figure 6.10. Interface3 (ARCH-CIVIL) in the DD phase of the SG project

In the construction documents phase, as shown in figure 6.11, there was little communication between the civil and architectural teams. Communication was limited to occasional emails between (L2) and (A1) and updates over the server of the latest site plan with utilities and landscaping elements. (L2) had access to the base model, but it was not of much interest to him unless there was a relevant modification such as in entrance locations, where (A1) would point that out in an email or quick phone conversation.

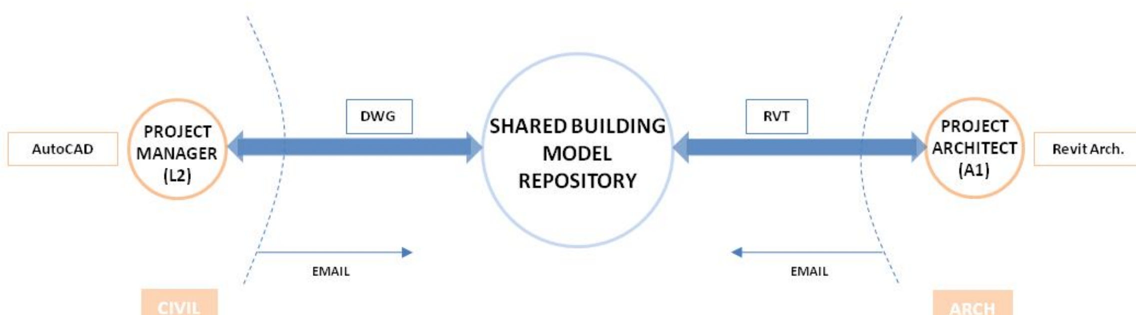

Figure 6.11. Interface3 (ARCH-CIVIL) in the CD phase of the SG project

6.3.1.4 Two Domain-specific Analysis Tools

As an example of this pattern of interdisciplinary interaction, the interface between key participants in the sustainability analysis team and the HVAC department in the MEP team is examined (interface 4). The main tools used at this interface were domain-specific analysis tools (such as Ecotect and EQuest for the sustainability analysis team, and Carrier HAP for the HVAC team). The tools at this interface were not consistent throughout the project phases. In schematic design, as shown in figure 6.12, the MEP team had still not received the base model, and so most of the HVAC work was focused on developing a narrative and sending it to the architect based on square footage information. The HVAC project manager (M3) attended the early engineering meetings to develop the HVAC systems and respond to key modifications by the client.

Being an in-house consultant and more in touch with the architectural team, sustainability analyst (E1) had access to the base model in schematic design. As the SG project was a LEED silver project, (E1)'s main objective was to setup the appropriate target values in Revit and the analysis tools he used to carry out the analysis till the LEED documentation phases. His interaction with (M3) was limited to meetings and emails in schematic design, and figuring out what analysis tools the HVAC team would be using for coordination purposes. (E1) used Ecotect for preliminary shading studies, specifically to figure out the building orientation that would yield optimum performance. This was done by exporting the Revit model to Ecotect using gbXML format.

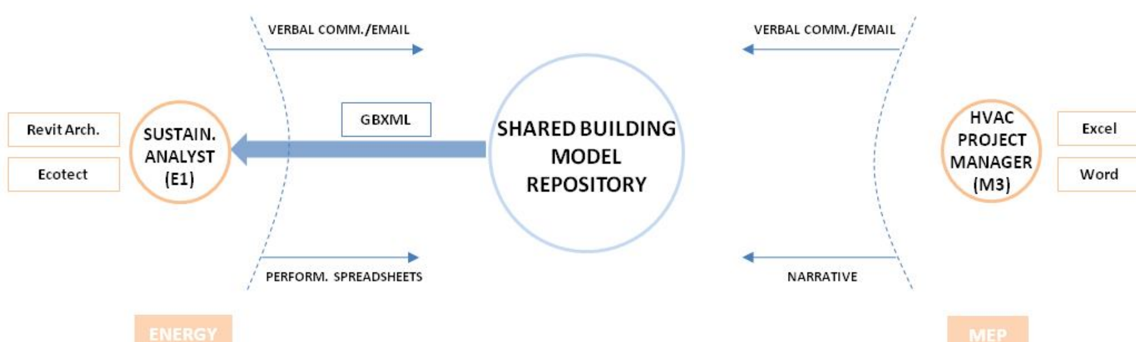

Figure 6.12. Interface4 (ENERGY-HVAC) in the SD phase of the SG project

In the design development phase, as shown in figure 6.13, an HVAC designer joined the HVAC department. In addition, an architect (M5) was hired by the MEP team to assist with Autodesk Revit MEP. His main task was setting up projects, linking MEP files to the base file, setting up templates and any kind of custom families that the MEP firm does not have, and setting Revit standards for the firm in general. In this phase, the HVAC team started using the Hourly Analysis Program (HAP) from Carrier for cooling and heating calculations.

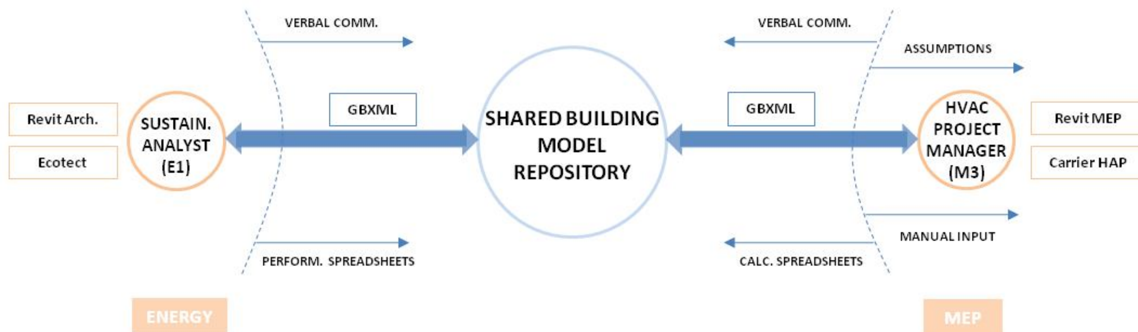

Figure 6.13. Interface4 (ENERGY-HVAC) in the DD phase of the SG project

Some incompatibility issues surfaced during this phase. First, as the HVAC team was aware of what ASHRAE calculation method their analysis tool employed, they were more confident and comfortable with its results than with Revit MEP. For example, (M4) ran loads for the same building and under the same conditions, and Revit was about 40 percent off. Second, any imperfections, inaccuracies in the export and translation process, or incorrect modeling for model elements such as wall or slab overlaps resulted in a lot of accumulation of error. It was much easier then to start from scratch in the HVAC analysis software than to fix those errors which could not be tracked.

Third, as the architectural team was not completely determined on specifics of model elements and their properties, they did not usually have all their parameters (e.g. type of glass, R-value, type of window U-values) embedded in the BIM base model. Generic objects were used instead, and this meant the HVAC team had to make a lot of assumptions, manually input some parameters and ask the architectural team and (E1) for more clarification. As (E1) was relying on the architectural team's model and on the same Revit parameters as input for Ecotect, where he carried out his performance calculations, there were many discrepancies between his results and the HVAC analysis results. This made it harder for him to interface with HAP, and the MEP team preferred starting from scratch and using their own calculations to acquire more accurate data.

In the construction documents phase, as shown in figure 6.14, (E1) started using EQuest for energy modeling, performance analysis and LEED documentation. There was a desire within the group to integrate Revit schedules with EQuest so that plans would be color coded to automatically indicate allowable energy consumption in response to any Revit model updates. This effort was not undertaken however as the group became short of one its members at the end of DD and beginning of CD, and the energy model was also outsourced to an external consultant who also used EQuest for energy modeling.

With the HVAC team taking over most of the effort of doing calculations of internal loads and performance, (E1)'s goal was to make sure at this point that they were using the right assumptions throughout this phase. Communication between (E1) and (M3) in this phase was mainly through emails, discussing amount of glazing, insulation values, and other detailing issues, but (E1) did not directly provide performance data for the MEP team. The MEP team was more reliant on their set of calculations and tools, and (E1)'s role became more focused on following the LEED documentation process.

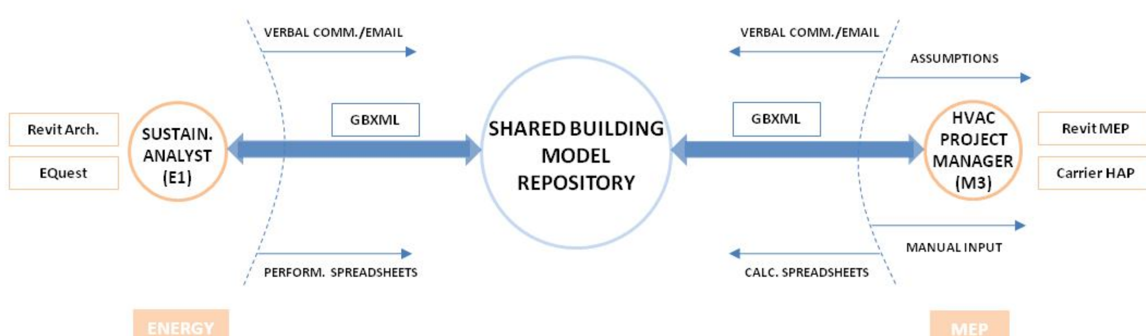

Figure 6.14. Interface4 (ENERGY-HVAC) in the CD phase of the SG project

6.3.2 Interfaces in Intradisciplinary Interaction

6.3.2.1 BIM-authoring Tool and Domain-specific Analysis Tool

As an example of this pattern of intradisciplinary interaction, the interface between key participants in the structural team is examined (interface 5). The main tools used at this interface were BIM-authoring tools (Autodesk Revit Structure) and domain-specific analysis tools (RAM Structural Systems). The tools at this interface were not consistent throughout the project phases. In schematic design, as shown in figure 6.15, both (S1) and (S2) used AutoCAD and RAM to develop a narrative and send out a rough layout and preliminary structural drawings. In their internal meetings, they sat mostly at the computer screen, opened the RAM model, and discussed lateral systems, seismic and wind data, types of foundations, and other issues based on geotechnical work.

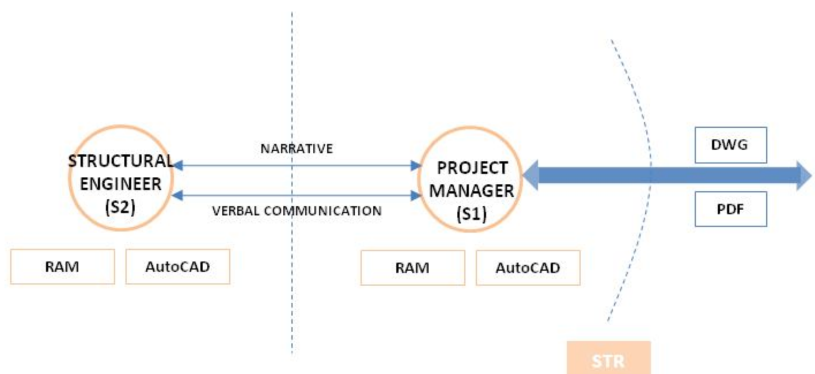

Figure 6.15. Interface5 (STR) in the SD phase of the SG project

In the design development phase, as shown in figure 6.16, (S1) and (S2) worked more according to the Revit updates they were getting from (A1). (S2) worked in both Revit Structure and RAM, while (S1) double checked some of the analysis results in RAM. (S3) represented technical support for the team, where he helped (S2) in setting up basic Revit families and templates. The main problem in this phase was the incompatibility between Revit and RAM. The process of updating the RAM analytical model with updates from the BIM base model was not by any means seamless. As the two tools come out of two different conceptual schemes (structural analysis versus modeling) and are products of two different software developers (Bentley and Autodesk), the process of automatically embedding the parameters, assumptions or results of one tool into the other was not possible. In order to communicate the model updates to (S1) for further analysis and checking, (S2) had to constantly input the modified parameters after every update from the architectural team as manual input into RAM; a process which was both exhausting and inaccurate. He would also print out an updated set of drawings for (S1)'s review. They would both discuss the updates over the printouts, and then (S2) would revise the structural model in Revit Structure accordingly.

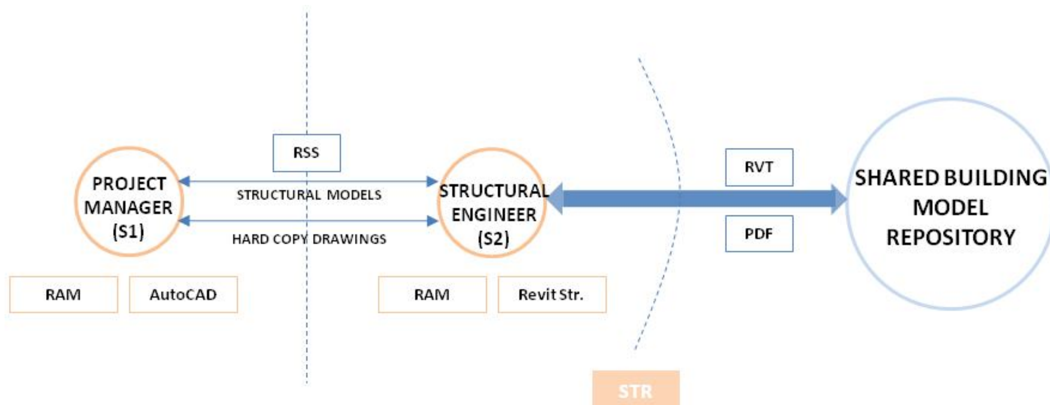

Figure 6.16. Interface5 (STR) in the DD phase of the SG project

In the construction documents phase, as shown in figure 6.17, (S1) continued to review printouts of the BIM base model. At this stage, (S2) would locate the architects' updates on the structural model, extract sections where modifications needed to be made, print those out and incorporate them in the hard copy set for discussion and review with (S1). (S1) would either meet up with (S2) frequently to discuss further steps or make manual markups on the hard copy and hand it back to (S2) to reflect those markups in the Revit model.

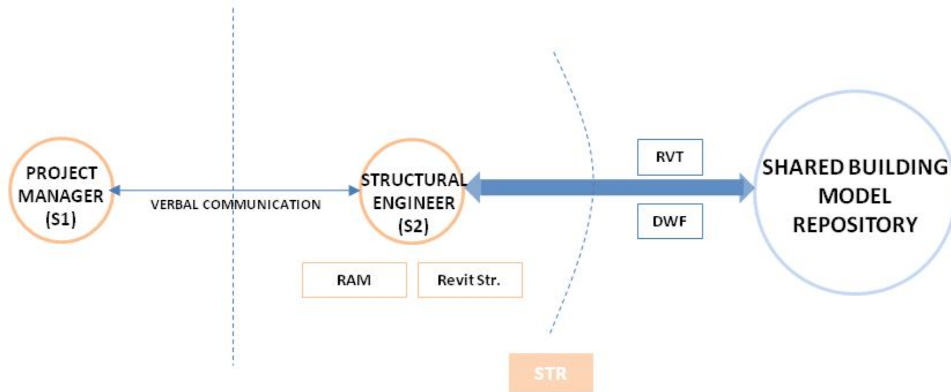

Figure 6.17. Interface5 (STR) in the CD phase of the SG project

6.3.2.2 BIM-authoring Tool and Sketches

As an example of this pattern of intradisciplinary interaction, the interface between key participants in the architectural team is examined (interface 6). The main tools used at this interface were BIM-authoring tools (Autodesk Revit Architecture) and other representations such as freehand sketches and rendered images. This interface involved a variety of patterns of communication across different participants. In schematic design, as shown in figure 6.18, each of (A3), (A4) and (P1) communicated information differently to (A1), who had to assimilate that information and translate it into the *language* of Revit Architecture. The least problematic was (A3) who had Revit experience and was comfortable with using Revit from the beginning of the project.

Incorporating ideas from (A4) and (P1)'s numerous sketches however was not an easy task for (A1). A lot of – and often faulty – interpretation of (P1)'s instructions and diagrammatic representations or (A4)'s freehand sketches and rendered photoshop images was involved. Added to that was the "designer – modeler" mode that (P1) inflicted on (A1), where the modeling effort became an indirect account of what (P1) *designed*, but which did not often turn out to be what was intended.

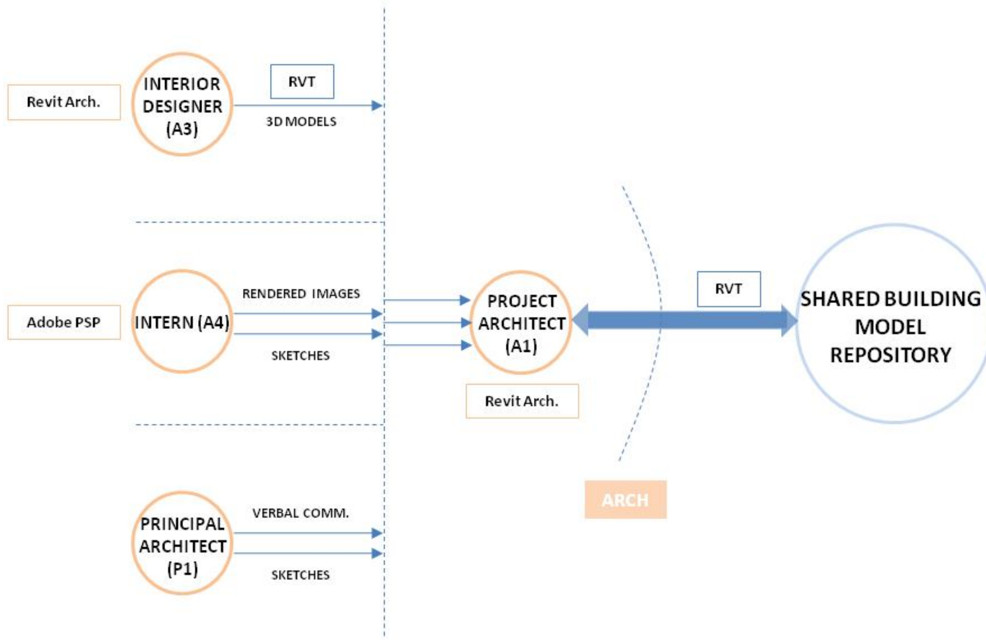

Figure 6.18. Interface6 (ARCH) in the SD phase of the SG project

In the design development phase, as shown in figure 6.19, the modeling and production load was too much for (A1), and so (P1) engaged (A4) in the Revit modeling process. (A4) had several obstacles, mainly struggling with Revit functionalities as a new tool, and being pulled off to work on other tasks in the firm. This instability in production did not introduce any more efficiency in terms of production, and (A1) had to carry out production work solely. (A4) continued to draw intermittent sketches as design ideas for specific portions of the project, and give them to either (A1) or (A3) to incorporate in the BIM model. In the construction documents phase, as shown in figure 6.20, the pressure on (A1) was increasing, and more help was needed on the modeling and production side. (A5), an expert Revit user, was hired to help both (A1) and (A3) with their tasks. At this point, the modeling effort was more of coordination work with the consultants and producing drawings and documentation, and most of it was done using either Revit or DWF files. There was very little intervention from (P1) except for minor refinement in detailing.

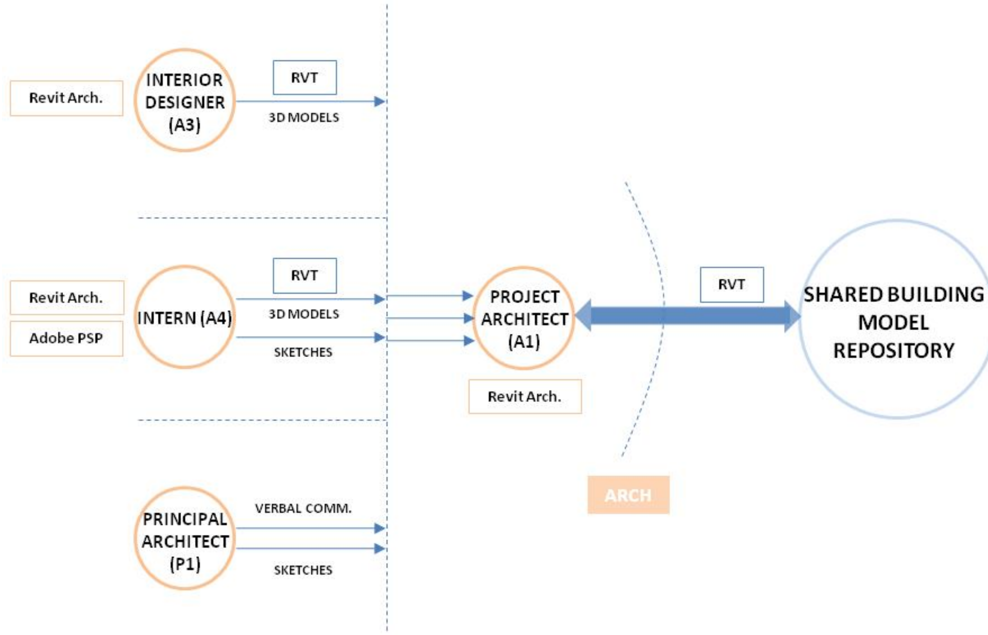

Figure 6.19. Interface6 (ARCH) in the DD phase of the SG project

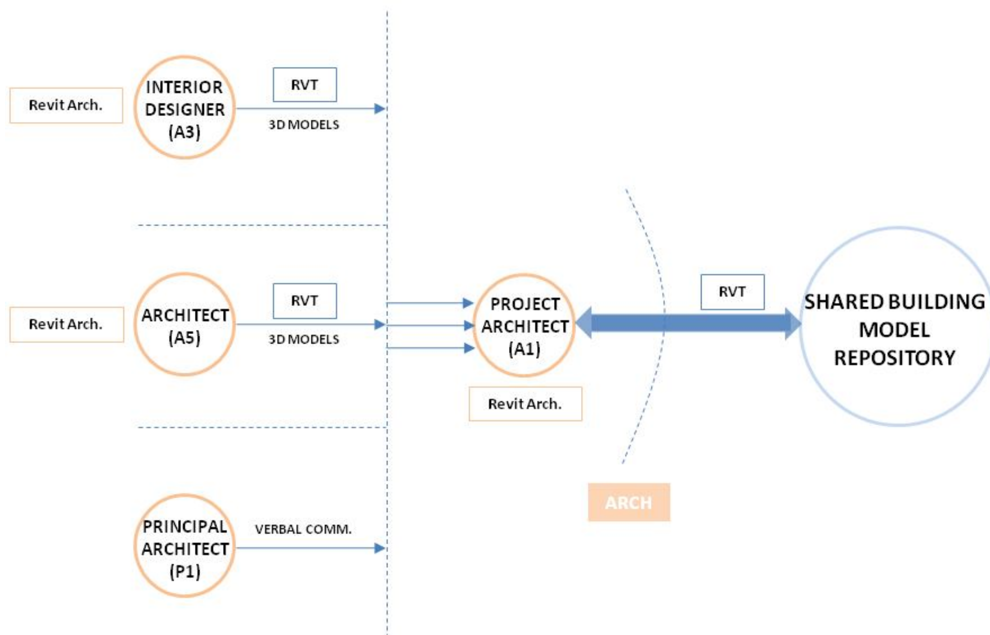

Figure 6.20. Interface6 (ARCH) in the CD phase of the SG project

6.3.2.3 CAD Modeling Tool and Domain-specific Analysis Tool

As an example of this pattern of intradisciplinary interaction, the interface between key participants in the civil and landscape team is examined (interface 7). The main tools used at this interface were modeling tools (AutoCAD) and domain-specific analysis tools such as HydraFlow. In schematic design, as shown in figure 6.21, (L1) and (L2) discussed the main approach to site utilities, landscaping, piping, and other site constraints that should be communicated, especially to the architects and the MEP team. Based on geotechnical reports from surveyors in the firm, some preliminary calculations done by (L2), and other documents from the state, (L1) set up the narrative for the schematic design phase including the site layout drawing in AutoCAD.

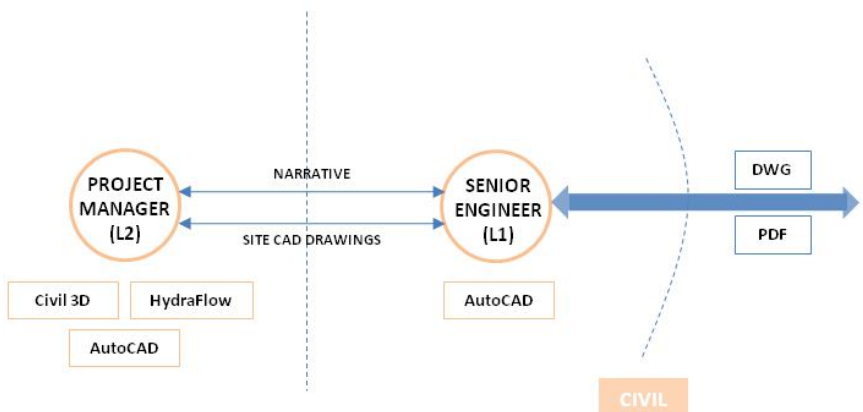

Figure 6.21. Interface7 (CIVIL) in the SD phase of the SG project

In the design development phase, as shown in figure 6.22, (L2) used HydraFlow and Civil 3D software for the piping and stormwater calculations. The software included 3D components such as terrain modeling and working with 3D site coordinates. Much of the reasoning behind the 3D construction of the site model from the analysis packages was concealed by the “flattened” site drawings that were dominant in the exchanges and discussions between (L1), (L2) and the rest of the team. (L2) extracted 2D site layout drawings from the analysis packages, imported them into AutoCAD, and worked through

CAD print outs and sketches together with (L1) and other drafters in the team on further refinements.

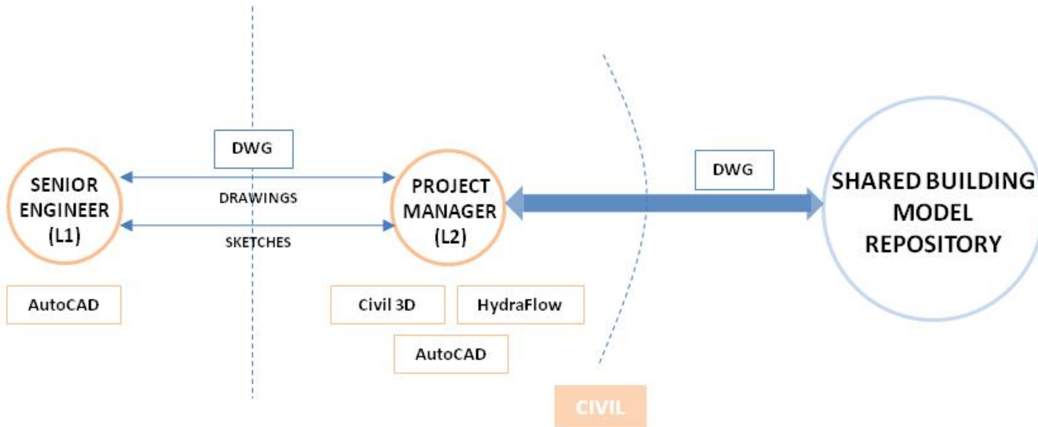

Figure 6.22. Interface7 (CIVIL) in the DD phase of the SG project

In the construction documents phase, as shown in figure 6.23, (L2) continued using AutoCAD as the main platform for updating site layout, site cross sections, plantation and hardscape drawings. The team drafters worked in AutoCAD, while (L1) and (L2) mainly coordinated the work over CAD print outs together, and brought up any issues for discussion with (A1) or (A2).

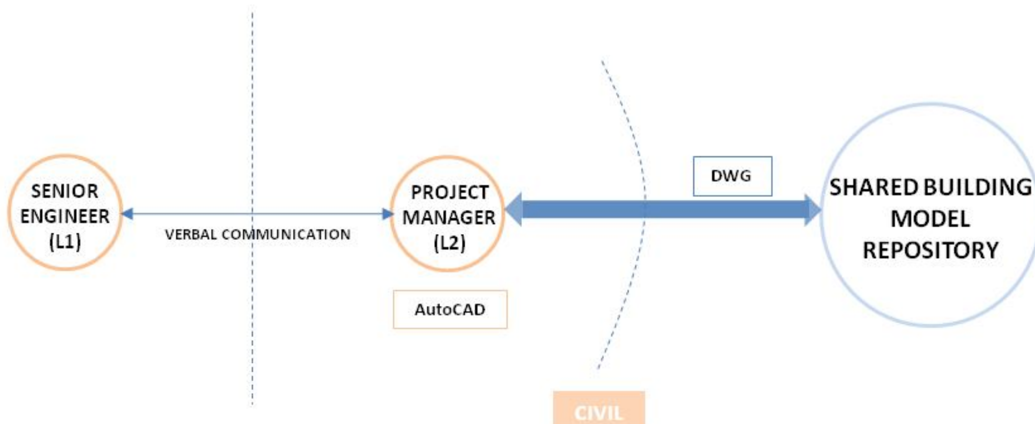

Figure 6.23. Interface7 (CIVIL) in the CD phase of the SG project

6.3.2.4 Domain-specific Analysis Tool and (Unexploited) BIM-authoring Tool

As an example of this pattern of intradisciplinary interaction, the interface between key participants in the audiovisual team is examined (interface 8). The main tools used at this interface were modeling tools (AutoCAD), domain-specific analysis tools (EASE acoustic modeling software) and BIM-authoring tools (Revit Architecture). This was not consistent throughout the phases. During schematic design, as shown in figure 6.24, (V1) was receiving the AutoCAD version of the SG project from (A1). He used the information from the CAD file and from precedent example projects in the firm to generate the AV proposal in narrative form, including preliminary AV conduit box locations, projection screens, duct work, and some specifications. (V1) also carried out a physical simulation of auditorium spaces in the firm to inform the process of designing those interior spaces. (V2) and other members of the AV team used the EASE acoustic analysis software to perform preliminary AV and acoustic calculations for the auditorium spaces. (V2) was also migrating CAD libraries to Revit Architecture families and setting up templates, as he believed it would be easier to work with the architectural team using Revit, especially with (A3) on the interior design of spaces.

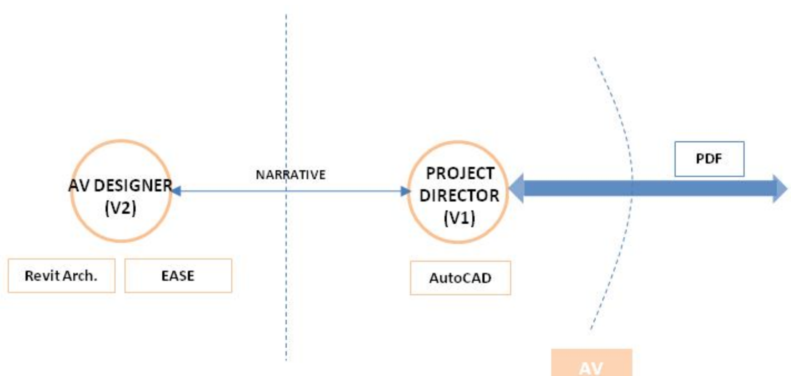

Figure 6.24. Interface8 (AV) in the SD phase of the SG project

In design development, as shown in figure 6.25, the effort done by (V2) in preparation for using Revit was not much integrated in the process, as (A1) had requested that the AV team only use AutoCAD and provide 2D DWG files. The work done by (V2) in Revit was all extracted by (V1) in AutoCAD. A lot of the reasoning behind the specific locations of projection screens, and parametric relationships related to floor height, sight lines and auditorium configurations were not preserved in this case.

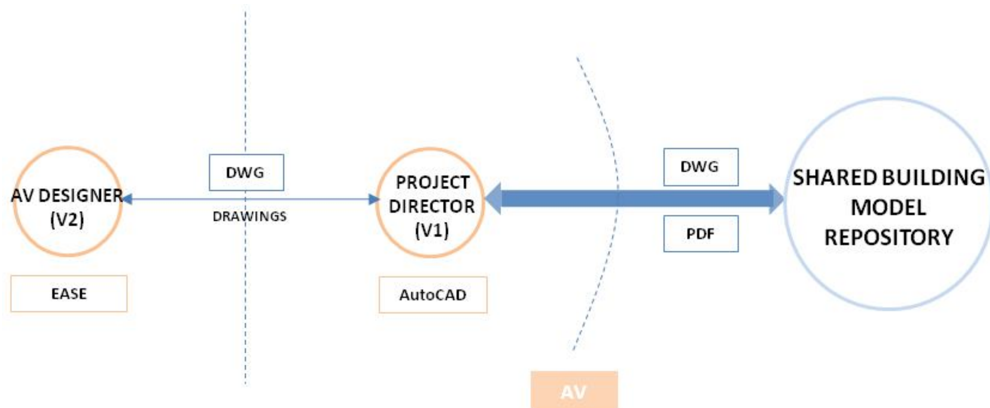

Figure 6.25. Interface8 (AV) in the DD phase of the SG project

In the construction documents phase, as shown in figure 6.26, (V2) continued to support the transition effort to Revit in other projects in the firm, while (V3) was directly involved with (V1) in the SG project. (V1) and (V3) continued to use AutoCAD to produce the AV drawings and document specifications.

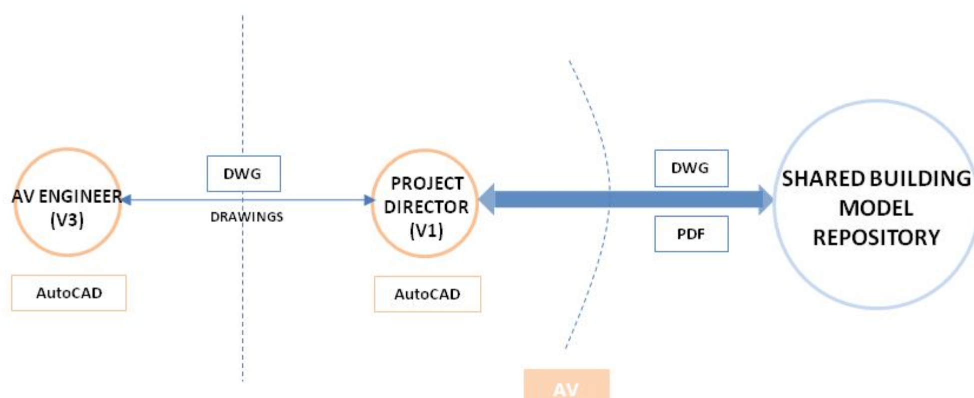

Figure 6.26. Interface8 (AV) in the CD phase of the SG project

6.3.3 Interfaces in Non-disciplinary Interaction

As an example of this pattern of non-disciplinary interaction, the interface between the client and key participants in the architectural team is examined. The main tools used at this interface were BIM-authoring tools (Revit Architecture). The participants were not consistent though throughout the project phases. During schematic design, as shown in figure 6.27, (A1) and the architectural team worked on the BIM base model, but provided the client (O1) with only hard copy drawings, PDF or PPT files that included basic plan, elevation and section drawings, narratives and specification documents. At this early stage, images and photorealistic renderings were one of the main means of communication between the architect and the client. (O1) provided the team with images of traditional buildings and other documents that represented his taste and the specific elements and motifs that he wanted to include in the SG project. (A1) and the team also presented images of precedent examples of similar buildings and contexts, in addition to renderings of similar projects done earlier at the firm. In meetings with the client, these images represented the shared space of communication, where a preliminary picture of the design approach was portrayed through the negotiation process over the different images and renderings.

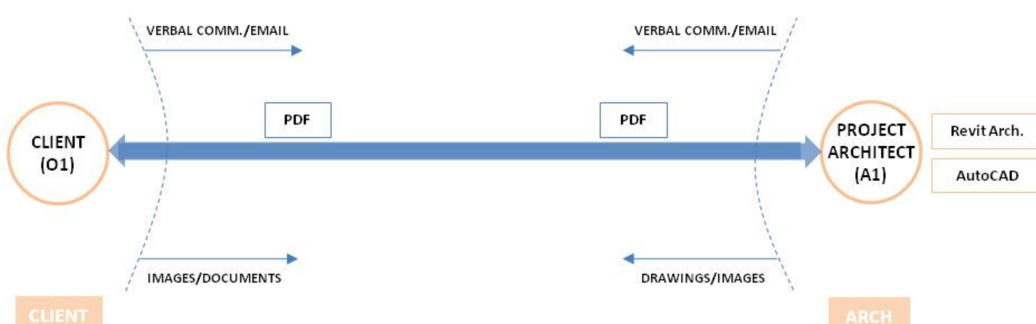

Figure 6.27. Interface9 (ARCH-CLIENT) in the SD phase of the SG project

In the design development phase, as shown in figure 6.28, there was a new client for the project (O2) who had a different approach in terms of the building form. He preferred a modern approach rather than a traditional approach, and this was reflected in the façade material requirements. The same method of communication however was in effect. (O2) and the architectural team exchanged images that reflected the client's taste. No RVT or IFC files were sent to the client in this phase. (A1) only sent hard copy drawings and PDF files of the design development package to (O2).

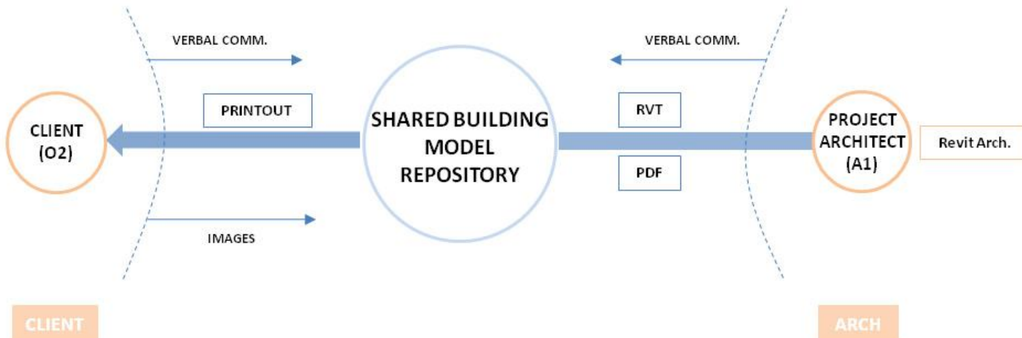

Figure 6.28. Interface9 (ARCH-CLIENT) in the DD phase of the SG project

In the construction documents phase, as shown in figure 6.29, there was little communication with the client. At the end of CD, the full documentation and drawing package was sent to (O2) in hard copy and PDF file format. The client therefore did not have any access to the BIM model throughout the project phases.

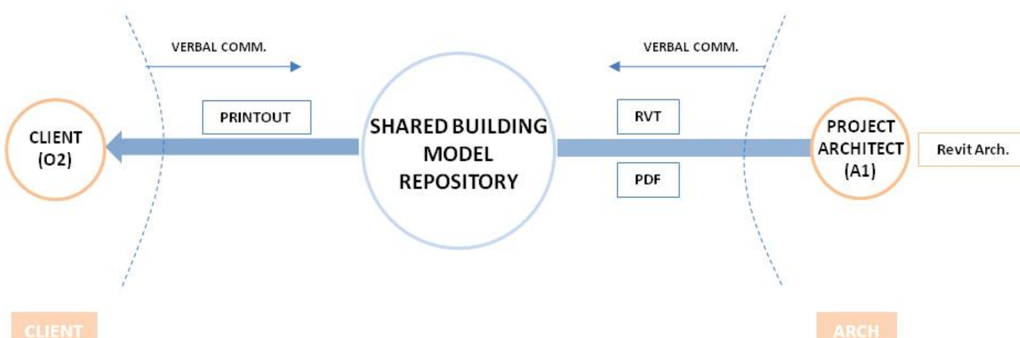

Figure 6.29. Interface9 (ARCH-CLIENT) in the CD phase of the SG project

6.4 The Shared Project Model Revisited

6.4.1 States of the Shared BIM Model

The interfaces demonstrated in the previous section denote patterns of communication that take place at the intersection or overlap between two or more disciplinary participants using two or more tools and representations. They include BIM-authoring tools at the focus of attention, but extend to include CAD modeling tools, analysis packages and other non-digital representations that come into play and interact with the base model. It was shown that these patterns are not just discrete "data exchange interfaces", but are always associated with a larger context of disciplinary interaction and communication, and involve socio-cognitive dissonances and variations on communicated information to match individual preferences or domain-specific interests. Some of the observed patterns were related solely to the computational capacity of the employed tools such as the incompatibility between BIM-authoring and analysis tools. Others were directly related to participants being not fully aware of the information needs of other disciplinary participants such as the interpretation of missing information and the need to provide additional domain-specific or customized parameters. Yet others were related to participants having to translate design information from one form of representation to another such as the aptitude of the BIM-authoring tool to convey what sketches and rendered images done by other participants could or vice versa.

These patterns were shown to reflect different types of interaction and over different phases. Interdisciplinary interaction for example comprised most of the tool incompatibility issues due to the diversity in modeling and analysis tools used. It also involved issues related to the understanding of information needs of other participants, as it was hard to fulfill the needs of all disciplinary participants. Frequent physical or virtual communication was necessary to confirm the exchanged information over the project server. Intradisciplinary and non-disciplinary interaction however comprised most of the issues related to translating design information or requirements from verbal instruction to modeling, or from one digital or non-digital representation to the other. Verbal communication was often the predominant method of communication among team members and with the client, and therefore a lot of interpretation was necessary to transfer and represent the intent in the BIM-authoring tool.

What does this mean then for the “shared project model”? In this emerging type of interdisciplinarity and intradisciplinarity where the boundaries of both specialization and design knowledge are becoming supposedly less and less distinct, who owns the intermediate space of collaboration and decision making? What are the characteristics or states of the shared model that well describe it in context and not just in terms of hypothetical capabilities of communication among two ends of a data transaction? Many studies have discussed the *completeness* or *correctness* of a shared BIM model in specific domains of interest. The notion of a complete or correct model is always viewed in relation to either computational capacity of tools or neutral format translators to carry an accurate representation of required datasets, or correct modeling of building elements and complete representation of input parameters by the user. This description tends to be accurate only when seen out of the context of interaction among disciplinary participants. I propose to expand these preconceptions and provide a description of the different *states* of a shared building model repository, seen in light of the dissertation observation. These states may occur separately or in conjunction at different phases of a project. They represent the conditions under which a shared BIM model reflects the nature of situated interactions of participants with tools and with each other at a given instant in the project.

<u>State (1): A complete model pending participant verification</u>

The BIM model may be complete and correct in terms of geometry, conventions and input parameters needed for teams sharing the model, but requires channels of communication supplementary and external to the model to confirm that all modeled elements correspond to the modeler's intention. This usually takes place in a mature phase of design when most of the decisions are made and the primary goal of model exchange is coordination with minor changes. In this state of the model and phase of the workflow, a high degree of precision is needed, and therefore both parties have to be fully confident that the information provided by the model is to the highest level of accuracy, where there is no room for unintended error or misunderstanding. With current BIM tools having no method to *detect* the original intention of the designer, this creates a space of ambiguity among disciplinary participants and potential for interpretation and speculation. Failure to confirm or refute the speculations of other participants sharing the model as a result of overlooking supplementary communication channels may lead to accumulation of error based on repeated assumption build up and personal interpretation.

State (2): A model with complete but potentially unreliable information for participants

The BIM model may be correct in terms of geometry, conventions and input parameters needed for teams sharing the model, but contains too much information that participants may or may not have intentionally embedded for use by other disciplinary participants. This usually takes place at early stages of design, where BIM tools may demand a much higher level of detail than is required at such phases, which does not necessarily guarantee that the participants embedded the suitable input for that stage of design. In this state of the model and phase of the workflow, an overload of possibly inaccurate information can cause an accumulation of error as other participants incorporate that information for the purpose of their analysis and calculations. The BIM model in this case looks right or complete in terms of required information, but may not necessarily reflect conscious design decisions made by either participant sharing the base model due to the early high demand of BIM tools for many input variables.

State (3): A partially complete model for coordination purposes using minimal information

The BIM model may be correct in terms of geometry, conventions and input parameters needed for teams sharing the model, but only partially complete, where teams agree on strategies that allow them to share only specific model elements and in a simplified way for coordination purposes. This decision usually takes place at the beginning and continues throughout the project, where teams decide what exactly is necessary to model and what can be described elsewhere and does not need to be modeled. In this state of the model, using conventions and workarounds in the BIM-authoring tool to describe intent without fully modeling every element may work for practical reasons among AEC consultants including easier and faster coordination.

The base model can be described in this case as a *minimum requirement* model, where only very basic and necessary information and 3D geometry is exchanged, while the agreed upon strategies and conventions among participants sharing the model, which remain internal to the model, complement this exchange mechanism. Although this represents an efficient approach and reduces modeling load, it may have a downside regarding the contractor's interpretation of the drawings, especially when methods of delivery eventually include the shared BIM model as the key reference. If all parties including contractors are not in sync, the effort done in the design phase may eventually end up in a remodeling effort by the contractor.

State (4): An incomplete model for conceptualization and reflection purposes

The BIM model may be complete or correct in terms of geometry, conventions and input parameters needed for teams sharing the model, but requires auxiliary representations external to the model, such as freehand sketches, physical models or quick renderings, to fully describe it. This usually takes place at early stages of design especially among members of the same design team, where the primary goal of the model exchange is visualization and reflection to develop a preliminary concept. In this state of the model and phase of the workflow, more exploration and reflection is needed with relatively low degrees of accuracy, whether the model was partially or fully modeled.

Although there are more and more conceptual components, interfaces and add-ons being introduced to BIM-authoring tools, the freehand sketch remains more effective in terms of *quick and dirty* expression and externalization of ideas at early design phases. BIM model representations remain for many participants, especially old school designers or inexperienced modelers, rich in information but poor as media for design reflection. In intradisciplinary interaction and during design brainstorming sessions, this becomes problematic, as BIM-authoring tools may be more restraining than enabling. With varying roles and levels of expertise within a team, the output may not necessarily reflect the full capacity of the thought process that the team spent endless hours discussing and articulating over auxiliary representations that do not *make it through* to the base model.

State (5): An incorrect model with respect to 3D geometry

The BIM model may be complete in terms of conventions and input parameters needed for teams sharing the model, but modeled incorrectly in terms of geometry. This usually takes place at stages of design development, where the primary goal of the model exchange is conducting analysis by other domain specialists. In this state of the model, incorrect modeling of building elements without the knowledge of participants and without methods developed to detect those errors can result in many inaccuracies that can render analysis results that do not correspond to the original intent built in the model.

Incorrect modeling may occur due to inexperience of participants with BIM-authoring tools and correct modeling, the lack of standards that regulate modeling procedures, or simply technical problems with BIM-authoring tools. In the first case, inexperienced participants may not be aware of modeling procedures that ensure a correctly modeled element. Errors that may seem trivial or unnoticeable such as duplicate spaces or overlapping walls can result in huge discrepancies and profound consequences for analysts who may easily operate on flawed geometry and produce inaccurate results. Even with more experienced participants, modeling with no clear regulating standards can cause inefficiencies. Standardizing templates, modeling procedures, and manufacturer models is substantial in reducing a lot of these inefficiencies, whether the standardization effort is done on a firm wide or project wide scale. In the third case, expert modelers may experience technical difficulties with modeling capabilities in some tools, such as intersecting model elements, and may not be able to overcome them if noticed. BIM managers may or may not resolve those difficulties within the project time frame. They sometimes ask software vendors for assistance but often with little success due to the time it takes to respond to a specific issue.

State (6): An incorrect model with respect to input parameters and conventions

The BIM model may be modeled correctly in terms of geometry, but not in terms of the conventions and input parameters needed for the other teams sharing the model. This may be due to the lack of understanding of some participants of the needs of other disciplinary participants, especially when the model involves the contribution of multiple entities. This usually takes place at stages of design development, where the primary goal of the model exchange is conducting analysis by other domain specialists. In this state of the model and phase of the workflow, this lack of understanding entails that the specialists manually embed in the model or analysis package a set of assumptions, parameters and other values based on domain-specific expertise that may or may not match the assumptions the participants had in mind originally.

These assumptions may then have to be revised continually by means of communication channels external to the base model. These revisions often take place later than needed, especially if designers pay little attention to implications of the parameters they input in the model, with the interests of specialists being only an afterthought rather than enlightening sources that constantly inform their decision making. As a result, reconciliation sessions and discussions are typically deferred and limited to discrete instances rather than continuous feedback loops throughout the project. By time, the parameters and assumptions built into the base model become obsolete, and it becomes harder to track the original intent or work with existing model information.

State (7): A complete model with misrepresented information propagated to participants

The BIM model may be complete or correct in terms of geometry, conventions and input parameters needed for teams sharing the model, but much of the information embedded in the model is lost in the translation process from one suite of tools to another due to incompatibility among those tools. This may be due to participants using different software modeling and analysis platforms in the exchange process, or due to limitations in translation capacity within one platform to carry the required information with fair accuracy. This usually takes place at stages of design development, where the primary goal of the model exchange is conducting analysis by other domain specialists. In this state of the model, failing to recognize these limitations in translation may lead to analysis results that do not match the initial intent built in the model. If recognized, participants may prefer to discard the automated translation and export of model data and manually input the parameters they need in their analysis tools. With frequent and continuous model updates, this may lead to a time consuming process with inaccuracies.

State (8): A complete model that represents a reduced dataset of information or underlying assumptions from other applications or participants

The BIM model may be correct in terms of geometry, conventions and input parameters needed for teams sharing the model, but may exclude some of the underlying assumptions used by other disciplinary participants or include elements from other modeling tools that are restricted to 2D geometry for simplification purposes. This usually takes place at stages of schematic design and into design development, where the primary goal of the model exchange is exploring alternatives and getting design feedback through analysis by other domain specialists. Specialists who are still in the transition phase to BIM may prefer exporting their analysis data in the form of 2D CAD drawings that are integrated in the base model, even if their analysis included 3D geometry. In other cases, their assumptions may be excluded if metadata from their analysis packages is not incorporated into the model, but rather a reduced dataset that only provides end results. In this state of the model and phase of the workflow, there may be practical considerations to simplify the model and not overload it with a lot of unnecessary 3D geometry, but preserving geometric relationships inherent to the design intent and to the related analysis and feedback may be more crucial. There may be many missed opportunities as a result of this abridged version of the base model in terms of informing the decision making process and providing useful feedback to all participating teams.

6.4.2 The Shared BIM Model as Boundary Object?

The interfaces demonstrated in section 6.3 depict part of a larger picture and concept known in sociology as boundary objects. According to Star and Griesemer (1989), boundary objects denote objects that are "both plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites". They carry different meanings and are interpreted differently across social communities, and at the same time carry common content in such a way that preserves their integrity and makes them recognizable to all those communities. Gal et al. (2004) broaden this definition of boundary objects to indicate "resources that form and inform social identities" that are encompassed in a dynamic system with components bound up in reciprocal relationships, rather than just translation devices that maintain coherence and address informational gaps between social communities. An immediate observation about the BIM shared model in the dissertation study would assume that it does not act as a boundary object for all participants or teams since not all of them used BIM-authoring tools in their practices, like the civil engineering and audiovisual firms. This may not necessarily be the case nor is it a subscription to the contrary. To understand if and how shared BIM models act as boundary objects between AEC participants, I put forward the following observations:

Boundary objects do not necessarily connect parties together only; they can act as both connecting and disconnecting entities. The shared BIM model, as seen in the SG project, was an enabler for coordination between the architectural team and the structural and MEP teams. This does not mean that it necessarily aligned their perspectives or built bridges between the views and meanings of its different participants and teams, which represent different communities of practice (Wenger, 1998). It can be argued that the shared BIM model connects different communities that do not originally belong to each other through standardization of information (Star and Griesemer, 1989). Information in this case is organized in such a preset format that allows each of the participants to engage with it locally, while the mechanisms of the model as a boundary object deal with translation of information to other parties and provide each party with the required subset of information, on both the semantic and geometric levels. A number of issues emerge in this type of communication. The social complexity and experience represented in the shared practices, interactions and boundaries among participants is not usually congruent with what Wenger calls "reified structures of institutional affiliations, divisions and boundaries". *Membership* of a specific community of practice, as pointed out in chapters 4 and 5, does not necessarily imply institutional (or disciplinary) affiliation but is rather defined through engagement in practice and formation of identity. The underlying structures however defining the mechanisms of translation and interfacing in a BIM model tend to address institutional categories rather than communities of practice. They are more inclined to adopt "institutional boundaries" that make definite distinctions between their affiliates and non-affiliates rather than "boundaries of practice" that undergo continual negotiation of meaning and allow for flexible participation.

In practice, communities sharing the model tend not to follow those institutional boundaries but rather often "blur" them through "peripheral" relations and interactions. Some instances in the SG project witnessed the act of blurring these boundaries, or the act of "brokering" (Wenger, 1998). (A1), (A2), (B1), (E1) and (V2) are different but striking examples. According to Wenger, brokers open new opportunities for meaning and help coordinate and establish new connections across different communities of practice. Rather than being at the heart of a practice, they tend to stay at the boundaries of multiple practices, with the main enterprise being that of alignment and enabling transactions between conflicting interests, causing some element of learning along the process by introducing aspects of one practice into another. Although (A1) was at the core of the architectural team, there was an interesting shift in his role starting from design development and through construction documents. He was not the project manager, whose role is known to be mostly associated with brokering across practice boundaries, but he eventually highly participated in those activities as he was the most proficient with modeling and model coordination. He shared this role with (A2) but his share was often more dominant as he was "in control" of the main boundary object and reached out to consultants to reconcile practical issues – and not their perspectives – using simple coordination procedures. As (A1) was more involved in modeling and design than (A2), being in this position was more of an enabler for both design and communication, since he was involved in more details of coordination with the consultants.

(B1) represented a different kind of "brokering" role. As BIM manager, he was literally at the boundary of multiple practices and watching closely the conflicts and misalignments that were taking place for instance between (C1) and the architectural team. His focus, especially at the end of design development and beginning of construction documents, was primarily coordinating between the two "communities", enabling transactions between their arguments and misunderstandings, and helping to bring them together through more social engagement and learning more about each other's practices. There were other attempts by (B1) to facilitate the coordination process between the team and the consultants, as he did with other teams in the firm, by trying to introduce conflict detection software. Being just at the boundary of both practices with limited authority, he was isolated to a large extent from all parties, including the architectural team, and the decision was mostly up to (A1) who preferred to use other more easy-to-use methods within the BIM-authoring tool based on his experience.

(E1)'s role was yet different. He overlooked multiple projects in the architectural firm, sometimes working on 6 or 7 projects at the same time. His role was characterized primarily by its "multi-membership". As his work was mostly at the boundary of both architectural and MEP (specifically HVAC and electrical), he belonged simultaneously to both practices *and* to neither. His experience in both areas enabled him to make repeated attempts to bridge the gap between them in terms of shading and performance studies. Incompatibility issues between the BIM-authoring tool, energy analysis tools and the MEP analysis tools altogether introduced major redundancies to his brokering role. Again, his limited authority and his relative isolation from all parties in terms of active participation allowed the MEP team to take the decision of relying completely on their own tools and interact directly with the architectural team.

(V2) presented another example of brokering. As seen in chapter 4, his multi-membership in both the tool (boundary object) and another "community" (interior design "community") besides his original audio-visual design "community", opened up opportunities of negotiation in his participation in the project. According to Wenger, (V2) was caught between being attracted by the boundary object to become a "full member" of the interior design community of practice and being rejected as an "intruder" by (A3) and (A1) who wanted to maintain their design "space". The shared BIM model in this case “reified” the activity of integrating interior space configuration and the associated calculations into the audio-visual design of the space to an extent that allowed for a seamless, automated and meaningful activity for both parties. The balance however between acquiring enough legitimacy to participate and leaving enough distance to bring a different viewpoint to the table was not carefully managed by (V2); regardless of the fact that only the architectural team used the BIM-authoring tool, which was only due to contractual agreements.

Sharing the BIM model does not guarantee however an act of “collective brokering”, where connections are sustained between all practices and all conflicts are reconciled and addressed. Based on the observations in chapters 4 and 5 and the identified activities of *reading of*, *reading into*, *writing for*, and *writing to*, in addition to the interfaces of information exchange outlined in section 6.3, I suggest that the BIM model as boundary object in the SG project resulted in the emergence of different types of interchangeable participants, including what I call the “participant writer” and the “participant reader”, in addition to Wenger’s “broker”. The *writer* represents any participant contributing to the boundary object, which may be in this case not only the shared model but any other auxiliary representation such as a sketch, CAD model or image. Writers have full control or authority over what is “written” to the boundary object, but *readers* “receiving” the message at the other side have only partial control based on interpretation of what the message actually means to them. This applies to the states of the shared model mentioned in section 6.4.1 where incompatibility and interpretation play the major role. As the authority over the content and interpreted meanings of the different boundary objects is shared among the different participants, including writers and readers, the need for brokers becomes inevitable for coordination and alignment purposes. The three roles can be interchangeable over time and based on the relation of the participant to the different boundary objects that predominantly shape the structure of interaction in each design phase. For instance, in terms of interdisciplinary interaction in schematic design and early design development, the consultants were mostly passive readers of (A1)'s writing to the boundary object (the shared model), with some exceptions like (V2) who acted as broker between (V1) and (A3). In later phases, most of the architects and consultants were both writers *and* readers. With more conflicts and with the need to resolve issues and misalignments resulting from the boundary object or from discrepancies in perspectives, new brokers began to evolve in the scene, such as (B1) who acted as broker between (C1) and (A1), (M5) who acted as broker between both (M2) and (A1), and (E1) and (M4).

Within the architectural team, (A1) and (A3) were writers throughout the design phases, while (A4) was primarily reader in most phases but writer in other boundary objects such as sketches and rendered images. Her role changed to both writer and reader in design development using the BIM model as boundary object but only temporarily. Due to her inexperience, (A5) appeared as broker between (A1) and (A4) to resolve the incompatibility issues between them in terms of understanding each other's views about the design and expressing them accurately in the shared model. In fact, (A5) and (A1)'s roles in design development and construction documents were mostly a mix of all three types with different shares. With the client, the architectural team acted as readers trying to interpret the ambiguous requirements through mutually exchanged images between both parties. (P1) transferred those exchanges within the team by acting as broker, trying to convey the client's needs as much as possible through sketches to the rest of the team. (A4) augmented the brokering, especially between (P1) and (A1) where the shared model often failed to convey (P1)'s ideas, by using additional sketches, physical models and rendered images to bridge the gap between the design parti attempted by her and (P1) and the "mechanical" modeling procedures that (A1) was continuously undertaking.

With both (multiple) boundary objects and brokering being at the core of shared perspectives and ideas, they act as both enablers and obstacles to the effective communication of design intent among participants. The sequence of experiencing each tends to define how successful this communication is. For instance, in the interaction between (C1) and (A1) as per state (6) in section 6.4.1, the key boundary object was the shared BIM model where (A1) updated the model and (C1) extracted information relevant to his estimating procedures. As (A1) *wrote* the input parameters to the model, (C1) as *reader* did not fully accept or recognize some of those parameters as meaningful to him. As communication with this boundary object did not seem to satisfy (C1), the focus was shifted to another *reliable* boundary object that was more familiar and comfortable to him; Excel spreadsheets, and with another participant (A2) who acted as broker to resolve inconsistencies between both parties. Over spreadsheets, (A2) conveyed (C1)'s requirements to (A1) to redesign within the allotted budget. By time, this method did not prove as effective as there was still a disconnect between the *writing* of both (A1) and (C1). (B1) stepped in as broker to resolve the conflicts between both parties, but using other methods to develop the communication using the original boundary object; the shared BIM model, because he realized that a more consistent method of aligning the *reading* and *writing* procedures was needed. Through the sequence of reading, writing and brokering, and the how each boundary object lends itself to those processes, a clear idea of effective communication of design intent can be established.

6.5 Discussion

This chapter presented a reexamination of the shared project model based on the findings of the dissertation study. By providing a thick description of the different interfaces of participant and tool interaction enabled by the shared model, it was shown that the BIM model cannot exclusively embrace all interdisciplinary, intradisciplinary and non-disciplinary interactions for a given project. The description puts forward a series of states that the shared project model is assumed to operate within as per the study. These states highlight factors related to required channels of communication external to the model, possibly unconscious design decisions allowed by tool demands, the need for representations supplementary to the model for enhanced conceptualization, partial modeling of elements for efficiency and reducing the modeling load, incorrect modeling due to inexperience, missing conventions due to lack of understanding of needs of other participants, data loss or misrepresentation due to incompatibilities between tools, and excluding underlying assumptions from other tools or participants. Although these factors all contribute to the correctness and completeness of the shared model and to the reliable exchange of information among teams, they stem from different origins, including tool functionality and interoperability limitations, participant inexperience, lack of clear modeling standards, and the need for supplementary communication and representation of information.

The chapter also introduced the notion of the shared model as boundary object. Along with other boundary objects enacted in communities of practice and the writing, reading and brokering activities of participants in boundaries of practice rather than institutional boundaries, the effective communication of design intent among interdisciplinary, intradisciplinary and non-disciplinary participants is described through the sequence of events and along project phases. In this context, interdisciplinary interaction denotes interaction between participants belonging to – or are *members* of – more than one *typical* discipline. Similarly, intradisciplinary interaction denotes interaction between participants who are *members* of one *typical* discipline, and non-disciplinary interaction denotes interaction between participants who are not necessarily part of a specific discipline. These types of interaction do not appear to capture the full experience of multi-membership of participants to different communities of practice and the overlapping of their backgrounds, needs and goals upon communication and exchange of information. With the BIM base model as a key boundary object among others, and with the emerging interests and needs of participants who are members of different communities, new communities of practice yet started to evolve along the course of the SG project.

These new communities extend to include one or more of these three types of interaction. In section 6.3.1.2 for example, (A1) and (C1) are members of two different communities; architectural and cost estimating/contractors' community. At the same time, they both are members of the community of the architectural firm with its practices and shared resources. (B1), who acted as a broker at the end of design development and beginning of construction documents between (A1) and (C1), was a member of the firm but also belonged to a community of BIM managers and IT specialists. Throughout the construction documents phase, a new *secondary* community of practice started to build up from these initial *primary* communities. This secondary community started to develop a goal of its own, which focused on the enhancement and installation of a new cost estimating approach that allows for a more efficient design-cost feedback process. This goal is both independent from the initial goals set typically at the beginning of the project (and therefore separate from the goals of each primary community), and an emergent goal that develops only upon the interaction between some or all participants in each primary community. At the same time, in design development, a new community that included (C2), (S1) and (C1) started to evolve. Discrepancies in cost analysis results surfaced throughout the interaction between (C2) and (S1) due to different viewpoints on the level of both primary communities and individual perspectives. These discrepancies led to the instigation of a new secondary community among (C2), (S1) and (C1) with the goal of reconciling estimating methods and analysis results originating from the same building model; a goal that was not initially defined for either primary community from the beginning of the project. In fact, each of the interfaces identified in section 6.3 represents, in one form or another, a secondary community of practice that is not solely defined by the involved disciplines or tools but by the dimension of time and phase of interaction. As the tools and key participants at each interface change periodically, the nature of the activities (writing, reading and brokering) and communication taking place between participants, the boundary objects at the interface, and the *members* of the interacting communities undergo continuous transformation. In section 6.3.2.2 for instance, a subset of the primary community of intradisciplinary interaction (P1, A1, A3, and A4) worked in the schematic phase of design on developing the main concept of the SG building. The boundary object was not just the BIM base model. In fact, sketches, rendered images, and physical models were more of a shared boundary object, at least for most members of this secondary community. (A1) and (A3) were the main writers to the base model, while (P1) and (A4) were the main writers to sketches and diagrammatic representations. (A1), (A3) and (A4) were readers of the sketches developed by (P1), while most of the team were reading into (A1)'s model representations. (P1) and often (A2) – who was at the periphery – intervened as brokers to resolve the tensions between (A4) and (A1) and their different perceptions and readings of the multiple boundary objects during the interaction. In design development, the same members of the secondary community worked together, but mostly shared the same boundary object, as (A4) started to engage in modeling. In construction documents, (A5) joined as a new participant, replacing (A4) and therefore a new secondary community was established with three experienced modelers. (P1)'s role was limited to following the progress of the design through verbal communication. The BIM base model became the main boundary object at this stage. Brokering was limited, and there was a better reading of the model and the design than reading into the embedded meanings.

Secondary communities are thus developed as subsets of interdisciplinary, intradisciplinary or non-disciplinary interactions. According to the dissertation study, they evolved as a response to specific goals that were not originally intended from the beginning of the project, and therefore represent more *emergent* than *designed* activities and practices (Wenger, 1998). They were also related mostly to either technology development purposes or for the purpose of discussing specific design issues that were of interest to specific participants within or across different primary communities. Although the changing nature of activities in both primary and secondary communities, and the role of multi-membership in each, all affected the definition of BIM as boundary object, other dimensions seemed to contribute to that definition, such as time and phasing, and the existence of other *secondary* boundary objects. The shared BIM model played different roles in different design phases. It seemed to satisfy the notion of “nexus of perspectives” (Wenger, 1998) for some communities, but only in interdisciplinary interactions in later phases of the design. In that case, it was dominated by secondary boundary objects in early phases of the design and was less *meaningful* for members of those communities. For others, it was more meaningful in the conceptual or design development stage. This *partial* representation of the model as a boundary object with different relative weights in each design stage contributed to the various dynamic types or states of the model mentioned in section 6.4.1. The fact that it represented a different value for members of different primary or secondary communities added to the richness of the model as boundary object, and augmented the process of *participation* and *reification* (Wenger, 1998) embodied in community members and the model respectively.

As defined by Wenger, participation denotes active involvement by participants in a specific practice, while reification involves capturing and abstracting those complex practices into more concise and well structured representations for a better sharing experience within the community. Meaning making has always been associated with the duality of participation-reification. From the dissertation study, multi-membership and mutual recognition among participants belonging to different and overlapping communities of practice has augmented the sense of participation in the project. This was also achieved by some of the activities that the BIM tools and other secondary boundary objects shared by different communities allowed, such as information sharing, conflict resolution, and model coordination. In terms of reification, the model provided different values and levels of interpretation for members of different primary and secondary communities of practice. This represented challenges for the hypothetical automated process of sharing and coordinating information, it introduced more complexity and did not necessarily introduce less information chaos. *In principle*, the BIM model as a shared repository of information, and consequently a boundary object, is assumed to take into consideration all the participation and reification activities, and especially for the purpose of interdisciplinary interaction. However, the convoluted meaning making processes, and the goals, expectations and intentions of multi-member communities entails much more interaction patterns that are not necessarily captured in current BIM systems. These patterns vary across other contexts of study and within the larger population of firms that use building information modeling in their practices. The aforementioned differences in multi-memberships, values of BIM for different members, participation and reification activities, and the structure of primary and secondary communities of practice, all imply that these differences should be accounted for in technology development efforts. Chapter 7 introduces parallels to other contexts of study in an attempt to identify those differences within the larger AEC population by means of a definition of the main assumptions of the dissertation study and an investigation of current market reports that address the use of BIM in AEC firms to date.

CHAPTER 7

DESCRIPTION OF STUDY IN RELATION TO OTHER CONTEXTS

This chapter discusses the assumptions central to the dissertation study in relation to a spectrum of possible scenarios across other contexts within the larger population of AEC firms. To draw parallels to these contexts, the chapter examines existing surveys and market reports that address the use and benefits of BIM in the AEC industry in light of the dissertation findings. Amendments, supplements and thicker descriptions are proposed for the survey topics. Topics under investigation include the internal business value of BIM, the top ways to improve value of BIM, and the impact of project factors on BIM value.

7.1 Assumptions and Context of Study

The issues pointed out in the previous sections built on the findings of a single observation involving a number of participating AEC disciplines. In order to draw more generic conclusions and expand to include the larger pool of architectural and A/E firms in BIM-enabled practice, the key assumptions central to the research and its basic context and settings have to be demonstrated. These will be discussed in relation to a spectrum of possible scenarios across other cases, as follows:

Type of firm: The firms involved in the SG project were an architectural firm and a group of engineering firms. Other contexts of study may involve different types like architecture/engineering (A/E) firms where all disciplines are represented within the same entity. In this type of firm structure, many issues related to the nature of communication and model exchange among participants emerge. The fact that all disciplines exist physically or virtually under the same entity implies different communication channels and different mechanisms and strategies for design, planning, analysis, feedback, coordination, and conflict resolution. It is necessary to identify these differences in A/E contexts.

Software platform and version compatibility: Most of the participating teams in the study who used BIM-authoring tools used Autodesk Revit platforms version 2010 (including Revit Architecture, Revit Structure, and Revit MEP) and were in the process of moving to Revit 2011. Analysis packages included EQuest and Ecotect for sustainability analysis, Innovaya Visual Estimating and Timberline for cost estimating, Visual for photometric calculations, EASE for acoustic modeling, Carrier HAP for heating and cooling load calculations, RAM Structural Systems for structural analysis, and HydraFlow and Civil 3D for terrain modeling and stormwater management.

Some participants saw the transition to Revit 2011 problematic as they were just getting to learn Revit 2010, such as (M2), (S2) and (A4), especially with the new interface and learning other functionalities. Others saw benefit in Revit 2011, related to enhancements in coordination functionalities such as copy monitor (applying copy monitor to equipment and not only building elements) in case of (M4), or in being able to automate LEED target values based on ASHRAE requirements in Revit as with (E1). Some participants used tools from different platforms or software vendors, such as the structural team which used Revit Structure (a product of Autodesk) and RAM Structural Systems (a product of Bentley), and not for example Autodesk's Robot Structural Analysis, which presented compatibility problems.

Autodesk Revit is one of the most common platforms currently used in BIM projects in the AEC industry. Other contexts of study can involve different BIM-authoring tools such as Bentley Architecture, Digital Project, Nemetschek's Graphisoft ArchiCAD and Vectorworks, or other emerging tools. The key concepts and functionalities of each of these tools have to be taken into consideration in other contexts. While Revit's central project database approach implies coordinating all building elements in a single central file with multiple user access through localized files and worksets, Bentley Systems adopts an integrated project model approach that encompasses a family of application modules, Graphisoft adopts the virtual building model approach with ArchiCAD viewed as one of multiple satellite applications orbiting a virtual building model, and Vectorworks provides a general purpose and highly customizable software platform for BIM and CAD platform. Each of these BIM-authoring systems comes with its own suite of tools as well as its specific functionalities for conceptual modeling, parametric design, coordination, server technology and multi-user access. Specifics related to advantages and disadvantages in use have to be tested in the context of everyday practice.

BIM and non-BIM participants: In the dissertation study, three of the participating firms used BIM-authoring tools in the observed project (architectural, structural, and MEP). Two firms did not use BIM-authoring tools (civil and landscape, and audiovisual). This was specified according to the contractual agreement at the beginning of the project. Among the BIM participants, the architectural team was the most experienced with BIM-authoring tools. The firm had been undergoing the gradual transition from Bentley Microstation to Autodesk Revit for a period of four years, until most teams in the firm started using Revit in their projects. Usually at least one expert BIM modeler was assigned for each project. For the SG project, (A1), (A3) and (A5) had Revit experience and worked on several BIM projects earlier. The team received technical support from two BIM managers and other experienced architects within the firm. The firm also offered Revit classes for inexperienced participants like (A2) and (A4).

In the structural firm, the team and the firm at large were new to Revit or to any BIM-authoring tool. The SG project was the second or third BIM project in the firm. One structural engineer with Revit experience was assigned to provide technical support for (S2) and for all other teams working in Revit in the firm. The MEP firm also had a similar experience with Revit. It was the second BIM project in the firm. An architect (M5) was hired to provide technical support. MEP was considered one of the few MEP firms using Revit, as it was still common to use AutoCAD in most practicing firms, and most firms were still resistant to BIM. In other contexts of study, the number of participant teams using BIM-authoring tools is significant. If one or more consultant teams are resistant to using BIM in a project, the whole process may become useless.

Complexity of project: The SG project was a relatively simple building in terms of structure, form and number of stories, but complex in terms of its function and equipment. The project includes a medical technology building where the main focus is on spaces and laboratories with highly sophisticated equipment such as biology, radiology, chemistry, surgical technology and opticianary spaces. The building consisted of three floors and mostly repetitive spaces except for one lobby and atrium at the entrance. In other contexts of study, discrepancies in project complexity have to be taken into consideration. Some projects have specific focal points that may affect modeling procedures or communication among teams and participants. These include issues such as parametric design for the building façade, performance and energy savings, high rise buildings, etc.

Number of central and local model files: The disciplinary teams in the SG project all worked from one central Revit file, referred to in the dissertation as the BIM base model. Each team had a local file that it extracts and detaches from the central file and then uploads to the central file after modifications and updates. The architectural team, including (A1), (A3), (A4), (A5) and (E1) worked using one local file. The structural team, including (S2) and (S3) worked using one local file. The MEP team, including (M1), (M2), (M3), (M4), (M5) and (M6), all worked using one local file.

In other contexts of study, it is important to recognize the number of central and local files used. Some MEP firms for example use one local model with different views, as was the case with the SG project. Other firms tend to use one local file for each department; one file for mechanical and HVAC, one for electrical, and one for plumbing. Also, each discipline in the SG project had its own local file. In some other cases, multiple disciplines may share the same local file and rely on synchronizing access. Each case affects the nature of communicating information across the models, in addition to the degree of accuracy and accumulation of error. Working with multiple local files in intradisciplinary interaction for example may lead to a higher percentage of accumulated errors or lead to less coordination.

Model exchange versus other modes of communication: In the SG project, the exchange of the BIM base model was mainly instigated at the end of schematic design and the beginning of design development. The architectural team, mainly the project architect (A1), provided updates of the model once a week during design development and mostly twice a week during construction documents. The consultants updated their models upon receiving the architectural model and uploaded them on average once every two weeks during design development and once a week during construction documents.
Physical meetings, phone conversations and email communication were more frequent among the consultants during construction documents, when more attention was paid to detailing and coordination. With the structural and MEP consultants, verbal communication, discussions and physical meetings were ongoing throughout the project phases. With others like the cost consultant, civil and audiovisual, as well as the client, meetings and discussions were rather discrete, at the beginning and end of each phase, with no continuous follow ups.

In other contexts of study, it is important to specify the frequency of exchanges in each type of interaction; interdisciplinary, intradisciplinary, and non-disciplinary. For interdisciplinary interaction for example, it is important to note the frequency of model exchange, email exchange, phone conversations, and physical meetings. For interaction within teams, it is important to consider informal discussions and the exchange of models, sketches and drawings as well. In all cases, the representations that the participants and teams typically use for communication the most should be identified (e.g. print outs, sketches, diagrams, 3D models, physical models).

Standards: In the SG project, there were no project or firm wide standards developed in the architectural team regarding modeling procedures, worksets, templates or families in Revit. As the BIM manager (B1) did not establish unified standards for the firm and the project manager (A2) did not develop project specific standards, this was a burden for many participants, including (A1) and (A3), who were used to following specific modeling standards at the firms they had worked at earlier. As model element libraries and families were not fully organized within the firm, (A1) had to search for the suitable ones on the Internet instead of the local digital library.

In other contexts of study, establishing organized standards for all participating disciplines can affect the correctness and completeness of the shared building model. It is necessary to identify the extent to which these are developed and whether they are set project by project by project managers or are consistent throughout the firms on a localized or global scale. It is also necessary to understand if there is consensus among the architect, consultants and/or contractors regarding standards related to the BIM tool.

Conflict detection and resolution: The method used in the SG project to check for conflicts between building model elements related to the different disciplines included a number of ways such as using the Revit copy monitor functionality, using PDF and DWF digital markups on Revit sheet views, and manual coordination using hard copy drawings, the most successful being the DWF markups. Although the architectural firm and team had access to Autodesk Navisworks and was encouraged by the BIM manager to use it for conflict resolution, the team preferred not to use it due to the overwhelming number of errors that have to be double checked by the team and the exhausting time consuming process. Other teams in the firm used Navisworks and spent endless meetings trying to “make sense” of the conflict checking reports generated by Navisworks. More important to them was that using the software at least forced the consultant teams to come together, look at the reports on the screen, and discuss the issues while everybody was on board.

In other contexts of study, it is important to define what method of conflict detection and resolution is use. Neither method completely guarantees that all issues are resolved, but each comes with a different modeling approach that can range from 2D intent drawings to full 3D modeling. The former involves exhaustive physical coordination and eyeballing of printed out drawings, while the latter involves an exhaustive computational process with overwhelming results. Both however provoke a certain level of confidence and control over the process in different ways. With 2D intent drawings, participants are more likely not to be fully aware of the consequences of the drawings in the coordination process as is the case with full 3D modeling. The degree of comfort or confidence with a fully automated report however versus a manual process of detecting conflicts may vary across participants and teams.

Project delivery and modeling strategies: The deliverables in the SG project were 2D drawings. No 3D models were to be submitted to either the contractor or the client. There was an attempt by the project funding agency to demand that the BIM base model should be submitted, but this did not come into effect, as there was nobody skilled enough to perform the necessary 3D model checking against the agency requirements. As this issue was brought up internally within the architectural team, there was discussion as to whether the approach should incorporate *complete modeling* or a model that just *looks right*. There was also consensus among the BIM participating teams concerning modeling strategies. The project architect (A1) led the effort and coordinated with the teams what elements are to be modeled and what does not necessarily need to be modeled.

The type of deliverables affected many decisions regarding Revit views and templates, and coordination efforts with the consultants. The final model was not a full 3D virtual representation of the project, but a basic model that contained spaces, exterior and interior walls, ceilings, slabs, doors and windows. Other elements such as furniture, equipment, screens, mechanical systems, and piping were not always modeled. In general, elements that did not "appear" in more than one or two views were not modeled, but were drawn and complemented in 2D sections and details. In other contexts of study, it is necessary to identify whether the method of delivery involves submitting a 3D model or just 2D drawings. There can be many types of deliverables for the contractor or client, including hard copy drawings, digital 2D DWGs, or 3D model files such as RVT or IFC. Deliverable file formats are often requested that do not necessarily match the software platform most of the consultants use. This is not always automatically solved by means of simple format conversion, and may require remodeling.

Having an accurate picture of what the method of delivery is for a given project will help indirectly in defining the degree of completeness and correctness of the shared base model and the level of accuracy by which it is drawn. It is necessary to define what the purpose of the shared model is; is it a 3D model but still acts as intent drawings? In other words, is it a model with "minimum requirement" 3D geometry but with coordination as basic use, or is it a fully interactive and intelligent system?

Role of participants: In the SG project, contributions to the BIM base model varied among participants. Participants like (A1) and (S2) contributed a lot in terms of modeling. (A4) for example did not, but was effective with respect to designing in the early stages. As more modeling contribution was needed, (A4) was replaced with (A5) who was assigned considerable modeling tasks. Over the course of the project, some other participants joined in the middle of the project like (M4) who joined the MEP team during design development, and (C2) as an external cost consultant who joined at the beginning of design development. Some others left as a result of the fluctuating economy such as (E1)'s assistant in the sustainability group. Others were on and off on the project, as was the case with the cost consultant (C1) and the intern (A4) whose help was needed urgently on other projects. It is necessary in other contexts of study to track these changes in numbers and roles of key participants in all teams, as it affects the pool of design and modeling expertise residing in the teams.

7.2 Examining Market Reports and Surveys

The previous sections show how communication in BIM-enabled practice is enacted within the working environment in a larger context of socio-cognitive interaction and not just discrete model exchanges and interfaces. Section 7.1 illustrated a first step towards transferring the findings of the dissertation study to other contexts. In order to draw parallels from this study to the larger population of firms, systematic surveys have to be developed for gathering information from representative firms and identify basic experiences and characteristics in relation to the research inquiry. This section looks at previous surveys conducted for the purpose of studying characteristics of BIM in practice, and introduces suggestions that address the specific inquiry of the dissertation. These suggestions take the form of amendments, supplements or thicker descriptions of existing survey topics. Conducting the survey and putting it into effect is beyond the scope of this dissertation, and is a topic for future work.

Recent surveys regarding the use of BIM in practice (McGraw Hill, 2009; NBS, 2010) have focused on the following survey topics: the improved productivity and value of BIM, the perceived Return on Investment (ROI), competitive advantage, growth in BIM use, investments in teams, rapid adoption of BIM, and owner and market demand. Architects, engineers, contractors and owners participated in these surveys and were asked to rank the survey items based on their relative importance. These topics are more related to the business value of BIM in the AEC industry, and not to the minutiae of communicating design intent among participants and teams. The goal here however is to examine each of these topics in light of the observation findings, and propose new categories and subcategories or introduce changes that address the research inquiry and are seen to be of added value to the survey topics. In each of the proposed surveys below, individuals from participating organizations, including owners, architectural and engineering firms, and contractors, will be asked to provide general information related to their organization and their specific use of BIM tools, based on the assumptions listed in section 7.1. Factors such as the type of firm, type and version of software platform, number of participants, method of project delivery, method of clash detection and conflict resolution used, method of model exchange, and the role of participants, will be integrated (table 7.1).

Surveys like McGraw Hill (2009) incorporate architects, engineers, owners and contractors as organizations and firms, in addition to other categories related to individual participants like experts and novices. The proposed categories integrate primarily individual participants with the purpose of highlighting specific roles within and across participant organizations as the population under study rather than a generic investigation of those organizations. Rather than for instance architectural firms, electrical engineers, or experts, a wider and array of representatives and a specific population can be included such as project architects, interns, estimators, BIM managers, HVAC project managers, interior designers, structural senior engineers, etc. Other roles that are not usually recognized can be identified such as architects at MEP firms, contractors at A/E firms, engineers working for the owner, etc. Understanding the structure and type of the organization is another added value, which implies taking into consideration whether for instance the firm is an overall MEP firm or one firm per trade, an architectural firm or an architectural/engineering firm, etc. Incorporating such roles and other potential roles that emerge in the AEC industry and are specified by participants adds to the richness of the gathered data from the survey topics highlighted in the coming sections of this chapter, and allows for an in-depth reading of the survey results in relation to the context of the organization, the specific roles of individual participants, the BIM-authoring and analysis software applications they use, the methods they use for modeling and conflict checking, the methods of project delivery, and other background information. In the surveys below, section 7.2.1 examines surveys that discuss the internal business value of BIM. Section 7.2.2 examines surveys that discuss top ways to improve BIM value. Section 7.2.3 examines surveys that discuss the impact of project factors in BIM value.

Table 7.1. Basic information sheet for participants in proposed survey

PARTICIPANT BASIC INFORMATION	
Type of organization belonging to	
Owner	
Architectural firm	
Architectural/Engineering firm	
Structural firm	
Mechanical/Electrical/Plumbing (joint)	
Mechanical/Electrical/Plumbing (separate: specify)	
Civil/Landscape design firm	
Acoustics/Audiovisual firm	
Cost estimation firm	
Sustainability analysis firm/group	
Contractor/fabricator	
Other (specify)	
Full number of staff in organization	
Role in organization (architect, intern, project manager, etc.) (specify)	
BIM user (YES/NO)	
Number of previous BIM projects worked on (if applicable)	
Primary software application used	
BIM-authoring software platform used (if applicable)	
Autodesk Revit	
Bentley Systems	
Graphisoft ArchiCAD	
Vectorworks	
Digital Project	
Autodesk ADT	
Other (specify)	
Analysis software package used (if applicable) (e.g. Ecotect, HAP) (specify)	
Method of clash detection and/or coordination used (if applicable)	
Use clash detection software (e.g. Navisworks, Solibri) (specify)	
Use BIM-authoring functions/add-ons	
Use digital file formats (PDF/DWF) (specify)	
Use hard copy drawings for coordination	
Project deliverables	
BIM 3D models (RVT, IFC, etc.) (specify)	
2D drawings in digital format (e.g. DWG) (specify)	
Hard copy drawings	

7.2.1 Internal business value of BIM

In this survey topic by McGraw Hill (2009), the relative importance of internal benefits for BIM users was under investigation. The survey items included issues such as marketing new business to new clients, overall better construction project outcomes, reduced errors and omissions in construction documents, offering new services, reducing rework, maintaining repeat business with past clients, younger staff's learning of how buildings go together is improved, reducing cycle time of specific workflows, reducing overall project duration and construction cost, recruiting and retention of staff, increased profits and fewer claims (table 7.2). In this particular survey, marketing and promoting BIM-related services were among the top benefits reported. Productivity benefits such as avoiding rework, omissions and errors at an early stage of design through virtual design and construction preceded other benefits related to reducing cost or saving time. Interoperability and functionality limitations were seen as the biggest obstacle to improve value.

Table 7.2. Relative importance of internal benefits for BIM users (after McGraw Hill, 2009)

RELATIVE IMPORTANCE OF INTERNAL BENEFITS FOR BIM USERS	
Marketing new business to new clients	
Overall better construction project outcomes	
Reduced errors and omissions in construction documents	
Offering new services	
Reducing rework	
Maintaining repeat business with past clients	
Younger staff's learning of how buildings go together is improved	
Reducing cycle time of specific workflows	
Reducing overall project duration	
Reduced construction cost	
Increased profits	
Recruiting and retention of staff	
Fewer claims/ligitation	

The items in this survey topic appeared to fall under four main categories: *profitability and business value*, *productivity and efficiency*, *learning outcomes*, and *benefits for design*. In light of the findings of the dissertation study, proposed categories and subcategories are illustrated in table 7.3.

Table 7.3. Relative importance of internal benefits for BIM users (proposed survey)

RELATIVE IMPORTANCE OF INTERNAL BENEFITS (proposed)	
Profitability and Business Value	
Marketing new business to new clients	
Overall better construction project outcomes	
Offering new services	
Maintaining repeat business with past clients	
Increased profits	
Hiring minimum staff with maximum performance	
Productivity and Efficiency	
Reduced redesign	
Early analysis feedback and detection of design problems	
Reduced coordination time	
Reducing cycle time of specific workflows	
Reduced overall project duration and construction cost	
Reduced print outs and hard copy drawings	
Reduced work in representations external to the model	
Reduced communication external to the model exchange	
Tracking information along the course of the project	
Completing more projects in less time	
Using precedent information from previous projects	
Fewer claims/ligitation	
Learning outcomes	
Gaining collective expertise in using the tools	
Younger staff's learning of how buildings go together is improved	
Better understanding of needs of other participants	
Benefits for design	
Enhanced conceptualization and perception of project	
Handling more projects with complex geometry	

In the *productivity and efficiency category*, the following subcategories were proposed as supplements to the existing survey:

Reduced redesign: this refers to the amount of time that architects or consultants can save by not having to go back and make significant changes in the design as a result of inconsistencies of communicating information to and from each other. These inconsistencies can be due to software incompatibility or lack of mutual understanding of what the teams require with no adequate follow up except in discrete phases of the project.

Early analysis feedback and detection of design problems: this refers to the benefit of catching crucial problems in the design such as major conflicts with mechanical or structural systems or major budget concerns early enough in the project to avoid consequences or accumulation of error as a virtue of virtual design and construction. Sharing a building model among all consultants does not necessarily guarantee that the feedback from analysts takes place at an early stage, whether due to lack of coordination or tool limitations, as shown in this study. It is necessary to understand whether this is the case in other contexts of practice and what specific factors in software development or social interaction are likely to or is expected to affect the nature of the design and analysis feedback process.

Reduced coordination time: this refers to the effective coordination process between architects and in-house or external consultants. Coordination and conflict resolution can take different forms and can be either in the form of methods dictated by the tool or through strategies agreed upon by the parties sharing the model. It is important to realize which methods are seen to be more efficient in terms of coordination time for each of the participants in the different organizations. For instance, if most project architects see reduced coordination time as one of the top relatively important BIM benefits and they use DWF files for coordination and not conflict detection software like Navisworks, then that speaks to the advantage of one method over the other in terms of reduced coordination but does not necessarily guarantee for example reliable or *correct* coordination and resolution of conflicts. This survey item then has to be triangulated with other items related to coordination and with the same participants to achieve a comprehensive description of the coordination component of the survey.

Reduced work in representations external to the model: this refers to the efficiency of the BIM model in encompassing the mechanisms and workflow procedures sufficient to express, conceptualize and externalize design ideas and design information to other participants sharing the model. The assumption is that more and more reliance on representations that are not inherently integrated in the model such as freehand sketches and drawings renders the BIM model as being used solely as an *execution* medium rather than a *design thinking* medium. This could result in inconsistencies, where the full record of design decisions and history does not lie entirely within the shared repository but in scattered representations that are not accounted for internally in the model. Results from different participants may vary significantly among participants. Ranking this survey item as relatively important indicates the importance of representing and modeling a considerable amount of design elements within the model, while the opposite indicates the necessity of external representations and developing interfaces between both representations for a smooth and flexible workflow.

Reduced communication external to the model exchange: this refers to the efficiency of the BIM model in terms of conveying the required information to participants sharing the model. Reporting this survey item as relatively important denotes implicitly a high level of confidence with the model information, geometry and modeling activities by the participants without having to confirm with others sharing the model using auxiliary channels of communication.

Tracking information along the course of the project: this refers to the consistency in representing model information, whether through participant input or tool incompatibility at different levels of detail, such that analysts and consultants can follow the progress and development of design elements along design phases. For instance, if most cost estimators report both this survey item and the reduced communication item as relatively important as benefit, then that could indicate potentially a disconnect between the architect and the estimator with respect to keeping track of design changes affecting cost. Triangulation with other survey items will add more detail to the reasons behind the disconnect in terms of tool development or social interaction.

In the *learning outcomes category*, the following subcategories were proposed:

Gaining collective expertise in using the tools: this refers to the mutual and accumulated learning experience that is built up during social interaction and augmented through technical support within and across organizations. Reporting this survey item as relatively important indicates effective collaboration among participants and potentially *collective brokering* where most participants contribute to resolving tensions between those sharing the model especially with respect to the tool learning experience.

Better understanding of needs of other participants: this refers to the role of the BIM model in augmenting the learning experience of participants with respect to recognizing the information needs of others sharing the model. Reporting this survey item as relatively important indicates a potential role of the shared BIM model as boundary object, where the model contributes positively to aligning different perspectives and building bridges across different communities of practice to better understand what each community requires and avoid misinterpretation of communicated information.

In the *benefits for design category*, the following subcategories were proposed:

Enhanced conceptualization and perception of the project: this refers to the role of the BIM model in advancing the participants' ability to perceive and reflect on their design ideas. It is necessary to understand how different participants report this survey item, and which participants see the tool as an obstacle to conceptualization versus an enabler of design thinking.

Handling more projects with complex geometry: this refers to the role of the BIM model to manage unconventional building geometry (e.g. huge number of model elements as in high rise buildings or urban scale sites, or free forms with highly complex geometry or parametric functions). It is necessary to understand how different participants perceive the importance of this challenge to BIM-authoring tools.

7.2.2 Top ways to improve value of BIM

The survey items for this topic included issues such as improved functionality and interoperability, more clearly defined deliverables, more internal staff, firms and entry-level staff with BIM skills, more owners asking for BIM, reduced cost of BIM software, more readily available training in BIM, the willingness of authorities having jurisdiction to accept models as deliverables, and more use of contracts to support BIM and collaboration (table 7.4). In this particular survey, software related issues including better interoperability between applications and better functionality were on top of the list, including users from most disciplines and both experts and novices as well.

Table 7.4. Top ways to improve value of BIM (after McGraw Hill, 2009)

TOP WAYS TO IMPROVE VALUE OF BIM	
Improved interoperability between software applications	
Improved functionality of BIM software	
More clearly defined BIM deliverables between parties	
More internal staff with BIM skills	
More owners asking for BIM	
More external firms with BIM skills	
More 3D building product manufacturer-specific content	
More use of contracts to support BIM and collaboration	
More incoming entry-level staff with BIM skills	
Willingness of authorities having jurisdiction to accept models	
Reduced cost of BIM software	
More readily available training in BIM	
Integration of BIM data with mobile devices/applications	
More readily available outsourced modeling services	

The items in this survey topic appeared to fall under four main categories: *improved interoperability*, *improved functionality and interface*, *contractual agreements and method of delivery*, and *skills and training* (table 7.5). *Improved modeling* was added as another category based on the dissertation study. Overall, the categories discuss issues in software development, regulatory procedures, and improvements in the workplace.

Table 7.5. Top ways to improve value of BIM (proposed survey)

TOP WAYS TO IMPROVE VALUE OF BIM (proposed)	
Improved Modeling	
Specific standards to regulate modeling procedures in BIM tools	
Unified convention systems for BIM tools	
Devising software to check BIM models for correctness and completeness	
Defining modeling level of detail standards per design phase	
Improved Interoperability	
Improving translation capabilities between tools from different BIM vendors	
Improving translation capabilities between modeling and analysis tools	
More BIM-specific follow up meetings between teams to discuss requirements	
Improved functionality and interface	
Incorporating sketching interfaces in BIM tools	
Flexibility in modeling commands and methods	
Less front end setup and parameter input	
Contractual agreements and method of delivery	
More owners asking for BIM	
Willingness of authorities having jurisdiction to accept and check models	
More clearly defined BIM deliverables between parties for each phase	
More use of contracts to support BIM and collaboration	
Model submission in platform-independent neutral file format	
Skills and Training	
More internal staff with BIM skills	
More external firms with BIM skills	
More readily available and directed training by BIM managers	
More incoming entry-level staff with BIM skills	
Documenting project specific experience with BIM tools for reference	
Reduced cost of BIM software	

The *improved modeling* category was seen as essential to integrate, as it discusses regulatory procedures to guarantee correct and complete models. Proposed subcategories include the following:

Specific standards to regulate modeling procedures in BIM tools: this refers to organizations devising standards for modeling methods and procedures for *correct* modeling among its participants or participants of another organization. Firms may devise standards for using specific templates and libraries, or following specific modeling functionalities and procedures within the BIM-authoring tool for all projects, per project type or according to the standards of the client, contractor or another consultant. The purpose is to avoid unintended modeling errors that may lead to misinterpretation of information by other participants sharing the model.

Unified convention systems for BIM tools: this refers to the effort of developing a consistent and coherent set of conventions (with respect to names of spaces, types of doors and windows, manufacturer data for engineering models, etc.) among participants sharing the model, primarily architects and consultants, to maintain the semantic integrity of the model information throughout the phases of a given project. Reporting this survey item as one of the top ways to improve BIM value for most participants implies the need for this consistency in order to resolve any conflicts or misinterpretations resulting from using multiple convention systems.

Devising software to check BIM models for correctness and completeness: this refers to the effort of clients, BIM software vendors or other organizations interested in developing BIM standards to put together intermediary software that ensures that BIM models are modeled correctly for specific operations throughout the phases of a project, for internal use that provides continuous feedback within the firm, for use with other domain-specific analysis packages, or to satisfy standards required by specific organizations.

Defining modeling level of detail standards per design phase: this refers to standardizing the requirements of model submission at each phase of a given project among most or all participants (e.g. a massing model with basic names of spaces and no details required concerning door type or internal walls in the schematic design phase). A clear and more detailed definition of these requirements for all participants can potentially reduce the misunderstanding concerning what information is modeled by participants based on conscious decisions versus what is assumed by others sharing the model based on expertise or miscommunication of the reasoning behind those decisions.

Proposed subcategories for *improved interoperability* include the following:

Improving translation capabilities between tools from different BIM vendors: this refers to the development needed to reduce the incompatibilities between software applications from different vendors, especially in those conditions where it is likely that those applications frequently *talk* together. For instance, in the SG project, (S2) preferred and was more comfortable with using Bentley's RAM Structural Systems, rather than an Autodesk product, while using Autodesk's Revit Structure as a modeling tool. In this survey topic, it is important to observe, in addition to the importance of this topic, the BIM-authoring tools and the analysis tools that the different participants use or prefer to use. This will give an indication as to which applications belonging to different vendors are more likely to be used by those participants and which are less priority items.

Improving translation capabilities between modeling and analysis tools: this refers to the development needed to reduce the incompatibilities between modeling and analysis tools by enhancing the translation capabilities in the exchange formats, reducing the limitations of BIM-authoring tools with respect to modeling errors and inconsistencies, and establishing standard conventions to be used by both BIM-authoring and analysis tools, or possibly integrating modeling and analysis functionalities in a single platform.

More BIM-specific follow up meetings between teams to discuss requirements: this refers to the social interaction component, where the purpose is to identify whether more physical meetings are required between designers, or designers and consultants, solely dedicated to discussing interoperability issues and developing workarounds or internal mechanisms to overcome existing incompatibilities. The "Revit round table" in the SG project is an example of such an effort.

Proposed subcategories for *improved tool functionality and interface* include the following:

Incorporating sketching interfaces in BIM tools: this refers to the importance of incorporating more user friendly interfaces in BIM-authoring tools and how the flexible sketching medium can be linked to the modeling and analysis pipeline in those tools, especially in early stages of design. In the SG project, (A4) called for more flexibility in accepting any type of representation that the designer is comfortable with and resolving the integration with modeling and analysis functionalities. Others like (A1) was content with the schematic design component of the BIM-authoring tool and felt it was sufficient to represent his design ideas at this stage of design. It is important to distinguish how relevant this survey topic is among different types of participants, and especially within the architectural community, for example between interns and architects.

Flexibility in modeling commands and methods: this refers to the effort required to facilitate the use of functionalities and modeling methods such that there are different paths that participants can follow for modeling elements without being constrained by the methods imposed on them by the tool. A number of participants in the SG project pointed out the frustration with the rigidity and one-way structure of commands that the tool forces them to use with no room for "improvisation". Others who were more experienced could use the tool functionalities efficiently and build their process ahead based upon the constraints of those functionalities. It is necessary to identify whether this is valid for the larger population as well, and what it means for different groups of participants.

Less front end setup and parameter input: this refers to the effort done to reduce the amount of setup needed beforehand in the BIM-authoring tool to define information at a level of detail that cannot be reached at early stages of design. Defining many parameters with often too much detail forces participants to input information that they may have not consciously meant or studied sufficiently.

Proposed and modified subcategories for *contractual agreements and method of delivery* include the following:

More clearly defined deliverables between parties for each phase: this refers to the concrete definition of deliverables and methods of delivery of the BIM model. The modification to the original survey topic incorporates defining these deliverables for each design phase in order to establish a norm for modeling work and level of detail for each specific phase. Rather than defining only a final format that many participants may overlook, working with a defined standard for each phase allows them to adjust accordingly at a relatively earlier stage and establish a more coordinated mechanism of interaction with other participants.

Willingness of authorities having jurisdiction to accept and check models: this refers to owners and client organizations ready to accept BIM models as an official method of delivery and take the necessary procedures to make that happen. The modification to the original survey topic incorporates checking those models for consistency and conformance with desired standards such as building codes, design guides, or other requirements and rules specified by the client organization. This entails that these organizations, in cooperation with software developers and research institutions, establish clear and well defined methods for this checking procedure and dictate the necessary standards and conventions for the guidance and use of all participants. It is necessary to explore how owner and client organizations respond to this survey topic to understand the validity of this step, as it defines many of the other topics such as developing regulatory standards and unified conventions, and will help push the standardization effort steps forward for firms to follow.

Model submissions in platform-independent neutral file format: this refers to the clear definition of what delivery as BIM model implies. Submitting files in their native format from Autodesk or Bentley products for example can cause inconsistencies for client or owner authorities accepting models as deliverables. Neutral formats like IFC allow a platform-independent medium that enables consistent viewing and checking of models against the required regulations. Firms must also be willing to submit such formats and will require a lot of work from BIM managers and technical support to ensure the efficiency of the process. It is necessary to understand how owners, architects, engineers and contractors respond to this survey topic to establish concurrence.

Proposed and modified subcategories for *skills and training* include the following:

More readily available and directed training by BIM managers: this refers to the necessary training effort within firms and other organizations. The modification to the original survey topic incorporates directed training by BIM managers or other IT experts that addresses specific problems or approaches from previous experience. Some participants in the SG project highlighted the deficiencies in existing Revit training classes for example in addressing workarounds and tips to achieve correct modeling or better coordination, where the core goal lies in conventional teaching of the tool functionalities and commands.

Documenting project specific experience with BIM tools for reference: this refers to the effort of documenting precedent cases of BIM projects or collective team history for future use. This can be highly relevant for architects and engineers for example by using preset templates or libraries developed in previous projects, and for analysts by using accumulated databases of formulas and calculation methods. It is necessary to understand how different participants perceive this survey topic.

7.2.3 Impact of project factors on BIM value

The survey items for this topic included issues such as BIM-knowledgeable design professionals, companies, clients and fabricators on the project, interoperability between software applications, project complexity, size, schedule and budget, previous experience working with other companies on the project, collocation of team members from multiple companies, and contract form that is supportive of BIM and collaboration (table 7.6). In this particular survey, interoperability and having BIM-knowledgeable designers on the project were seen as having the highest impact on BIM success and value on a given project.

Table 7.6. Impact of project factors on BIM value (after McGraw Hill, 2009)

IMPACT OF PROJECT FACTORS ON BIM VALUE	
BIM-knowledgeable design professionals on the project	
Interoperability between software applications used by team members	
Project complexity	
Number of BIM-knowledgeable companies on the project	
Contract form that is supportive of BIM and/or collaboration	
Project schedule	
Previous experience working with other companies on the project	
BIM-knowledgeable fabricators on the project	
Project size	
Project budget	
BIM-knowledgeable client	
Collocation of team members from multiple companies	

The items in this survey topic appeared to fall under five main categories: *project-specific details*, *participants with prior BIM experience*, *previous collaboration between participants*, *interoperability*, and *physical and virtual communication*. The proposed categories and subcategories are illustrated in table 7.7. Another category was added based on the dissertation study which was *personal experience with BIM tools*.

Table 7.7. Impact of project factors on BIM value (proposed survey)

IMPACT OF PROJECT FACTORS ON BIM VALUE (proposed)	
Project-specific Details	
Project size	
Project budget	
Project complexity	
Project focus	
Participants with Prior BIM Experience	
BIM-knowledgeable design professionals on the project	
Number of BIM-knowledgeable companies on the project	
BIM-knowledgeable fabricators on the project	
BIM-knowledgeable client	
Technical support for the project	
Personal Experience with BIM Tools	
Progress in learning the tool	
Level of comfort and confidence with BIM-authoring tools	
Trusting the automatic extraction of data and output of analysis results	
Previous Collaboration between Participants	
Previous collaboration between participants across organizations	
Previous collaboration between BIM-knowledgeable participants across orgs.	
Previous collaboration between participants in an organization	
Previous collaboration between BIM-knowledgeable participants in an org.	
Interoperability	
Interoperability between software tools used by members of the same org.	
Interoperability between software tools used by members of different orgs.	
Physical and Virtual Communication	
Collocation of team members from multiple companies	
Frequent meetings (weekly/bi-weekly) between all participating companies	
Coordinating project issues using the virtual BIM model	

The *personal experience with BIM tools* category was seen as essential to integrate in the survey, as it discusses the personal position of participants and their level of confidence in BIM tools, results and automatic extraction of model data. Proposed subcategories for personal experience with BIM tools include the following:

Progress in learning the tool: this refers to the individual and collective learning value that is built up during a given project, with the aid of BIM managers, IT support or simply interacting and exchanging experiences with other participants. The built up expertise during this process introduces an added value to not only the project in hand but also for future projects, for the organization at large, for marketing purposes and getting new projects for the organization. In the SG project, (A4) reported she did not make the utmost out of the learning experience as expected and therefore may be reluctant to use the tool or be relied on as an asset in subsequent projects. It is necessary to understand how different participants perceive this learning component, especially experienced designers versus interns or less experienced designers for example.

Level of comfort and confidence with BIM-authoring tools: this refers to the personal preference of tools and the level of comfort with using BIM-authoring tools. Some participants in the SG project highlighted the difficulties experienced when using some of the functionalities and capabilities of BIM tools. It is necessary to understand how each of the participants, using different BIM-authoring tools, respond to this survey item. This will not only address the individual discrepancies among BIM-authoring tools, but also narrows down the search for functionalities that are either frustrating or satisfactory for different groups of participants.

Trusting the automatic extraction of data and output of analysis results: this refers to the level of confidence that participants experience with the outputs and results generated by analysis packages. Having less confidence in those outputs and preferring to establish custom built tools to suit individual needs may be more practical and reliable during the process for some participants. Inconsistencies however may arise when trying to incorporate those tools with the BIM modeling and analysis packages. It is important to understand which categories of participants have these preferences.

Proposed and modified subcategories for *previous collaboration between participants* include the following:

Previous collaboration between (BIM-knowledgeable) participants within and across organizations: this refers to the types of prior collaboration and work experience that participants (within and across organizations) may have had with each other. This was reported to have a positive effect on the workflow and level of understanding among those participants in the SG project. This is taken yet to another level when those participants had previous collaboration on BIM projects and understand the details of modeling and coordination. New experiences were reported to often slow down the process. It is important to understand what each type of prior collaboration represents for different participants. For instance, experienced BIM users who report previous collaboration with BIM-knowledgeable clients as having a highly positive impact on BIM confirm the added value of prior experience in subsequent projects.

Proposed and modified subcategories for *interoperability* include the following:

Interoperability between software tools used by members of the same organization (and different organizations): this refers to the software development efforts done to resolve incompatibility issues between applications that different participants use (within and across organizations). It is important to understand how these two categories relate. If experienced BIM users for example report interoperability between tools used by members of different organizations having a higher impact than those used by the same organization, this potentially confirms that there are more problems and incompatibilities associated between BIM-authoring and domain-specific analysis tools.

Proposed and modified subcategories for *physical and virtual communication* include the following:

Frequent meetings between all participating companies: this refers to the importance of physical meetings of participants within one organization or across organizations. This implicitly explores the effectiveness of the shared BIM model in conveying the required information among participants. It is important to understand how participants perceive the relative relationship between the frequency of internal meetings with collocated participants (including in-house consultants) and meetings with participants from other organizations. Some participants in the SG project reported collocation as having a positive impact on collaboration and enhanced level of understanding. Although (C1) had problems with communicating to the architectural team and demanded meeting physically with the team, (C2) who was not collocated with the team seemed to have more problems and required much more questions through both virtual and sometimes physical communication.

Coordinating project issues using the virtual BIM model: this refers to the effectiveness of coordination and conflict resolution solely through the virtual BIM model with minimum reliance on other forms of representation or other communication channels. It is important to recognize how different participants and organizations perceive the BIM model as the primary source of coordination without the need to augment the coordination effort.

Conclusion

Points to be considered when moving to other settings within the larger population of AEC practices include project focus, size and complexity, type of firm, number of BIM and non-BIM participants, project deliverables, software version and compatibility, modeling strategies of participants, communication channels and model exchange mechanisms, and others. Parallels were drawn to these contexts based on existing surveys and market reports related to productivity gains and internal benefits of BIM. Proposed topics for integration in future AEC firm surveys focus on enforcing modeling standards and regulations, clearly defined deliverable requirements, format and modeling procedures per project phase, enhancing learning outcomes, improving tool interfaces to adapt to user preferences, improving interoperability between software applications for both interdisciplinary and intradisciplinary interaction, and documenting project specific experiences with BIM for future reference.

CHAPTER 8

CONCLUSIONS

8.1 Conclusions and Discussion

This dissertation presented an ethnographic study that was conducted with the aim of understanding the affordances and limitations in current BIM-enabled architectural practice with respect to communicating design intent among AEC teams working in interdisciplinary collaborative environments. To address this inquiry, the dissertation first presented an overview of BIM and how design intent is seen to be currently represented and communicated. It also reviewed systems and approaches from studies in the fields of design cognition, design computing and engineering related to the capture and representation of design intent. Most of these studies fell short of describing both how social interaction and representation of design information are enacted in BIM software systems, and how AEC design teams use and interact with these systems and with each other in BIM-enabled "communities of practice". The dissertation then looked closely at two aspects of BIM-enabled architectural practice: (1) the abstract information exchange mechanisms brought about by BIM-authoring tools and analysis tools to facilitate collaboration and interaction, and (2) the nature of social interaction, mechanisms of knowledge construction, argumentation and negotiation within and across AEC teams. The dissertation examined the gap between these two aspects with the purpose of providing a thick description of BIM-enabled practice environments and proposing recommendations with respect to both technology development and social practice.

The dissertation proposed that ethnographic observation and personas are well-suited as mixed methods to investigate the nature of communication of design intent in BIM-enabled practice, as seen in the day-to-day practices and interactions of participants and teams, rather than conducting quick surveys or case studies. The dissertation then dissected existing hypothetical models related to the notion of the shared project model offered by BIM. Based on (1) the observations of the ethnographic study, (2) a pragmatic reexamination of the different interfaces and boundary objects that exist among participants using the shared building model, and (3) an exploration of the study in relation to a larger population of BIM-enabled contexts, the dissertation puts forward the following findings. At the core of these findings and implications is the emergent theme of *in principle versus in practice*, identified along the course of the observation. In line with this central theme, each of the findings below highlights the hypothetical view versus the pragmatic view, where theoretical claims about effective communication and smooth flow of design information are informed and supplemented by observations from social interactions in practice.

Scope of Communication: Extended Communities of Practice

According to the dissertation study, it was shown that the communication of design intent in BIM-enabled practice takes place at different levels and not just interdisciplinary collaboration between AEC "typical users" or "typical disciplines" as some theoretical models indicate. It rather extends to include a broader spectrum of individuals, communities and patterns of interaction. Individuals, as shown in the study, are not just members of a typical discipline, and so the *generic* architect, engineer, owner or contractor is not necessarily the *standard* unit of analysis when it comes to information requirements, goals and methods. The notion of a typical "user requirement", exercised in information delivery manuals and exchange requirement documents for BIM practices, becomes disputed and open to interpretation. The scope of what defines a requirement is then not solely dependent on what a discipline would typically need as information or what the conceptual framework of that discipline dictates. Instead, it embraces a richer range according to the background, needs and goals of the participating individuals. This does not imply however an exhaustive tailoring of the model or its functionalities to the individual needs of each and every participant, but rather realizing the diversity within each discipline and recognizing a richer detail pertaining to groups of users with similar goals, experiences, approaches and methods, and not just abstract entities. The personas underscored in the dissertation study are only samples of many archetypes that could exist in the AEC industry. These can be augmented through additional cases of BIM-enabled environments or by means of the proposed survey.

It was also shown from the study that the observed patterns of interaction included one or a combination of more than one of the following generic types of interaction: interdisciplinary interaction (between participants belonging to more than one discipline), intradisciplinary interaction (between participants within one discipline), and non-disciplinary interaction (between some participants that do not necessarily belong to a specific discipline). There are yet more levels of interaction that emerged through the different combinations of interaction and through sharing the BIM model as a central repository among all participants. New intersecting and overlapping communities of practice began to emerge along the course of the project, often temporarily in specific segments and phases, as a result of both the common evolving interests among participants and the shared boundary objects between them like the BIM model.

Primary communities of practice were the communities that appeared to be well defined from the beginning of the project and more related to the disciplines of the participating teams such as the architectural community, the structural community, the MEP community, the civil and landscape community, and the audio-visual community. The goal of these communities altogether was working collectively on the project in hand. Within each community, the goal was pursuing the domain-specific component of the project in general. Other *secondary* communities of practice began to emerge. There was an overlap between participants of these communities with the primary communities, but they developed new specific goals and practices that were not originally intended beforehand. Some secondary communities of practice emerged for the purpose of discussing design problems of interest, such as the community developed between (A4), (L2) and some concrete manufacturers to discuss outdoor concrete structures, or between (A2) and (S1) to discuss exterior cladding, or between (A3), (M2) and the lighting manufacturers to discuss lighting in laboratories. In some other cases, secondary communities emerged for the purpose of technology development and advancing the workflow, such as the community developed between (A1), (B1) and (C1) to address inconsistencies with the information flow from the architects to the cost estimator and vice versa and develop better exchange mechanisms using the shared BIM model. These secondary communities of practice did not necessarily involve participants working on the project. (A3) for example, together with (B2) and one of the designers who had worked with (A3) on previous jobs, were part of another secondary community of practice focused around resolving problems with Revit functionalities that were related to her work in interior design.

The aforementioned implies that a wider spectrum of actors, patterns of interaction and communities of practice (with diversity in background and expertise, goals, needs, motivations and expectations) should be considered while designing BIM tools for a more *effective* method of communicating design intent among different participants. For software developers and researchers, this is significant, as the notion of the generic user requirement needs to be augmented. To achieve such an effective method, associations to *typical users*, *typical disciplines* and *typical interactions* should be revisited and expanded. These include typical associations related to generic capabilities for individual users only, such as parametric flexibility, visualization capabilities and tracking of information, associations related to discipline specific requirements and tasks only, such as extracting analysis data and coordinating engineering models, or associations related to interdisciplinary interaction only, such as conflict resolution and sharing model information.

Mechanisms of Information Exchange

According to the dissertation study, the BIM model offers a shared repository for communicating intent among different participants through the process of exchanging data. *In principle*, the model carries *all* the required parameters, attributes and design information that describe the design product and convey the intent of the participants. *In practice* however, it was shown that the abstract process of data exchange is not sufficient. An understanding of the dynamic roles and tasks of these participants during their interaction was required, and not only in terms of their background, experience and goals as per the persona description. The dissertation identified three types of participants whose roles were interchangeable throughout the project: the *writers*, *readers* and *brokers*. It was shown that these roles, added to the role of the BIM model, varied for each type of interaction and for each of the primary and secondary communities of practice identified in the context of study.

In the first type of interaction (interdisciplinary interaction between primary communities of practice), the BIM model was at the core of the interface between most of the teams, especially in the design development and construction documents phases. Interpreting and *reading* information from the model was a major component of this type of interaction. Although two teams (civil and audio-visual) did not contribute to the BIM model, they were actively involved as *just* readers. In other words, they were not *writers* to the model through modeling but *readers* of the modeled data for their internal use. The rest of the participants were continuously involved in one way or another; writing to and reading from the model. This was not enough however for a comprehensive understanding of all the exchanged information. Many parts of the "story" were overlooked upon these exchanges. For instance, what an architect writes to a cost estimator through the model may seem sufficient to the architect, but the estimator has to yet go through a tedious process of *reading* which involves understanding what that information means, *verifying* with the architect if his perception matched the intent, and *translating* what that implies to both communities of practice. In this example, the estimator, being an inexperienced BIM user, does not write back using the BIM model but either meets with the architect or asks for clarification, and then proposes suggestions verbally or using another form of representation (e.g. spreadsheets). Brokers, such as the project manager or BIM manager, intervene to resolve design issues or tool incompatibility issues that could facilitate the communication and allow for a reading-writing process that could describe the exchanged information more accurately.

The complexity of this type of interaction is that the architect for example, while updating the BIM model, does not write *only* to the estimator, but to all readers who are sharing the model. These readers may be experienced or inexperienced BIM users, collocated or non-collocated participants. Their interpretation of the information can be completely different, and their reactions are expected to vary. Even experienced BIM users can overlook some of the information in the model, go through the tedious reading process, and, if not aided by a broker or did not verify the exchanged data, may write back information based on mere interpretation, which can lead to accumulation of error.

In the second type of interaction (intradisciplinary interaction within each primary community of practice), the BIM model represented for most teams the final stage of a process written internally within each team in preparation for sharing it with other teams. For some teams it was at the core of the interaction and for others it was just at the *periphery*. For the architectural team for instance, the model was at the core of interaction often as a shared visualization and thinking space. For others such as MEP and structural, it was more of a medium that encompassed the outcome of all the internal calculations and thinking within other analysis tools, and so the analysis packages for them were at the center of attention and the model was at the periphery.

Most of the participants within each community were *readers*, whereas a few were *writing* to the model and exchanging ideas both with their co-workers and with the other communities. In the architectural team, most of the participants were engaged in writing *to* the model in one way or another. This included using the BIM-authoring tool or other forms of representation such as sketching. This resulted in that most readers were simultaneously engaging in some form of *indirect writing* to the BIM model; also valid in other teams where CAD drawings, domain-specific analysis models and verbal communication were all forms of writing indirectly to the model. The job of *brokers* in this case was to make sure that there was minimum miscommunication in this indirect writing between participants within teams. (A2) for example intervened to resolve the misalignments between (A1) and (A4) in their perception of the BIM model and what it represented for them in the brainstorming sessions and early design decision making phases. (P1) on the other hand encouraged (A4) to get more involved in modeling, as opposed to just sketching, to help reduce the problem of multiple interpretations coming from different sources and representations.

In the third type of interaction (interaction within each secondary community of practice), the BIM model was not necessarily always at the core of interaction. This type of interaction represented a subset of interdisciplinary or intradisciplinary interaction, but the *boundary object* in this case was not restricted only to the shared BIM model, and included analysis models, spreadsheets, and drawings. As these secondary communities were formed along the progression of the project, they comprised individual participants representing different communities of practice and overlaps in these communities. At least one participant in each new formed community acted as a *broker* between two or more participants from different communities of practice. For example, (B1) was in charge of resolving the conflicts between (A1) and (C1) to develop a reliable cost estimate that makes utmost use of the information both parties had by aligning (A1)'s *writing* with (C1)'s *reading* of that information. He established a database that addresses the conventions they agreed on and suits the new platform they were going to use in subsequent projects. (A2) and (S1) both acted as brokers in charge of resolving architectural and structural clashes in the model that (A1) and (S2) *wrote* and developed together. As inexperienced BIM users, (A2) and (S1) both had their own *reading* of the model. Through their meetings, which were over hard copy drawings, they conveyed their suggestions and views to resolve the issues to both (A1) and (S2) separately.

In the fourth type of interaction (non-disciplinary interaction), this was represented primarily between the architects and the client. In this type of interaction, the BIM model was rarely at the core of interaction, as the method of delivery was 2D drawings. The interpretation of client requirements through verbal communication and imagery was at the center of communication between the client, the principal architect and other architects in the team. As *readers*, participants in the architectural team were often receiving mixed messages due to the ambiguity of requirements. At the same time, and as the deliverables were in the form of 2D drawings, the client as *reader* was always getting a subset of the information from the model. (P1) played an important brokering role in interpreting the client requirements as much as possible for the rest of the team to ensure all were on the same level of understanding and that the team could successfully translate those requirements in the model.

In all these types of interaction and for each design phase, the BIM model represented a different and changing form of a *boundary object*. In interdisciplinary interactions, the model was considered superfluous by most participants as a shared medium in the early schematic design phase. With the development of phases and with the continuous mix of interpretation and action, the BIM model began to acquire its *meaning* as an artifact for all participants sharing it. In the construction documents phase, it represented a "nexus of perspectives" for most participants. In intradisciplinary interactions, the BIM model was more of a self-contained object, especially in schematic design. It represented a repository that just documented an external design thinking process resulting from brainstorming sessions and design meetings. In later phases, the model became more of a shared thinking space. There was less effort in aligning misinterpretations and resolving inconsistencies, but only a few participants were actually *writing* to the model, or translating the collective thought process into modeling procedures. Interactions within secondary communities of practice were often temporary interactions that emerged due to a certain need recognized by a group of participants from different disciplines. Some interactions did not even involve the BIM model at the center of the negotiation process between participants. Those involving the model were characterized by continuous and gradual give-and-take interactions that were facilitated by brokering. In non-disciplinary interactions, there was more interpretation involved than action. Abstractions of the model were at the core of the interaction rather than a full and rich representation that could bridge the gap between the participants' perspectives.

In each of these types of interaction, participants are *in principle* just exchanging information in the form of attributes, parameters and other geometric and semantic model data. *In practice*, this is augmented by activities that stem from social interaction and mutual recognition among participants, such as *writing to* the model, *writing for* other participants, *reading into* the model, *reading of* the model, and *brokering*. These activities are not standard but vary depending on the participants' experience, backgrounds and goals, and on the level of understanding of other participants' needs. They can yet vary in other contexts, where different settings, team structure, type of tools, scale of firm and other factors come into play. This implies that mechanisms of exchange in BIM tools should not only consider the abstract input of data from all participating parties or embedding of geometric and semantic data from generic entities, but take into consideration the social communication and conversation that takes place between different personas in each of the identified communities. The more *automated* the process of data import and export becomes and the more complex the model is, the less likely it is that participants are aware of all design decisions or of any misinterpreted or lost information. Conflict detection, model checking and pre-checking methods often only add more automation and inhibit human intervention.

Affordances and Limitations

The dissertation showed that the affordances related to communicating design intent in BIM-enabled contexts highlighted affordances with respect to the tool and others related to the collaboration among participants. On the other hand, limitations were shown to include primarily the cost of the tool for participants, the cost of the tool for teams, and the incompatibility among different tools upon interaction. Both the affordances and limitations varied however with regards to each of the patterns of interaction identified in the dissertation study. In the interdisciplinary interaction between primary communities of practice, the BIM model represented a shared repository of project information and its main affordances were related to collaboration affordances between the teams, such as conflict resolution and the coordination of information. Limitations specific to this type of interaction were related to tool functionality problems that allowed for decisions not necessarily intended by participants, interoperability problems that led to data loss or misrepresentation, and regulatory problems such as the lack of clear modeling standards and conventions to follow consistently for all participants. Other problems were related to social communication such as the need to recognize the exact needs of other participants, and the continuous need for supplementary means of communication to confirm the validity of the exchanged data, represent the underlying assumptions and consequently convey the intent of the designer to other participants and vice versa.

In the intradisciplinary interaction within each primary community of practice, the main identified affordances were the parametric flexibility related to continuous design and modification activities, the capacity to visualize building model elements and navigate in 3D space, workflow efficiency, geometric precision within one given model, and the extraction of useful information off of the model in terms of cost, performance and scheduling. The architectural team especially pointed out some additional benefits such as the capacity of the model to aid development of design alternatives, and the ability to track information throughout the design phases. Limitations specific to this type of interaction were related to the cognitive burden that participants experienced while using the model, the cost associated with embedding too much information in the model and being forced to make design decisions at very early phases, incorrect modeling due to inexperience, incompatibilities between modeling and analysis tools, and forcing all teams to extensively model their building elements in 3D. The architectural team highlighted additional issues as limitations, such as the need for forms of representation other than the model to convey information internally within the team, and the need to communicate with other participants within the team and not rely solely on information extracted from the model. Issues such as status within the team, peer pressure, expertise and the personal preference of tools often led to conflicts or a state of disconnect among team members.

In the interactions within each secondary community of practice, one of the main affordances was the alignment and resolution of conflicting views and multiple interpretations through both social interaction and technology development, with brokers being at the core of this alignment effort. At the same time, the brokers' expertise, previous work and collaboration experience with participants and personal preference of tools and methods, all had a major role in redefining their role as beneficial or just adding more conflicts and limitations. In the non-disciplinary interactions, issues that represented major limitations included status and system of authority, the ambiguity of client requirements and the need for multiple and alternative interpretations. As the BIM model was not essential in this type of interaction, there were missed opportunities that could have allowed for a better understanding for the client's taste and conversely as well in terms of getting informed feedback from the client regarding the progress of the project and its conformance with the requirements.

The dissertation also showed another major observation regarding affordances and limitations. Some of the identified categories represented a total fit as an affordance (such as visualization capabilities) or a limitation (such as incompatibility among BIM tools). Some categories however did not fit entirely into a genuine advantage or genuine disadvantage, but rather a mix of both with relative weights depending on the participants, the used tools, and the phase of the project. As a first example, "conflict detection and resolution" was mainly seen as an affordance with respect to collaboration among participants and teams. On the other hand, the mechanisms of conflict detection as seen in day-to-day practices were shown to exhibit both gains and drawbacks. Gains included resolving conflicts between different model elements and tracking changes. *In principle*, conflict detection and resolution methods were assumed to resolve *all* issues and conflicts among participants. This was not necessarily the case *in practice*, where there was a need among different participants for additional channels of communication external to the model to account for misinterpreted data or actions during the conflict checking process. Although this was considered as a drawback, it gave way for another added value, which was the *social glue* enabled by the tool. The automated and seamless detection and resolution of conflicts among different participants – which was the expected value *in principle* – was not fully attained, but the fact that those participants came together or communicated to discuss specific issues was an added value *in practice*.

This social glue, which was enabled by the multiple and intersecting communities of practice involved in this study, allowed for an augmented sense of *participation* embodied in the members of these communities (Wenger, 1998). Conflict detection and resolution in this case allowed for new experiences and active engagement in social enterprises through a process of constant negotiation, reconciliation, and development of workarounds in situ. As some participants indicated, if the BIM model forced them just to come together to discuss the issues, without having an *automatic* or *magical* way to resolve them, that was sufficient at least to draw their attention, get them to engage in discussions with multiple communities accordingly, and realize the mutuality of their participation. There was therefore a sense of action and connection, multi-membership, and mutual recognition that developed between participants of different status and who belonged to different communities.

As a second example, “incomplete information from the tool” was mainly seen as a limitation. On the other hand, it was seen to exhibit both drawbacks and gains in the context of day-to-day practices. Drawbacks included misrepresented or lost data among participants. *In principle*, completely represented model data guarantees an efficient representation of design information and workflow among multiple participants. This was not necessarily the case *in practice*. Although complete geometric and semantic information was needed by most participants, there was an implicit need for having enough space to interpret that information and make meaning out of it. In other words, this ambiguity was still valuable in overcoming the overwhelming sense of automation in data exchange mechanisms. This gave way for yet another added value *in practice*, where participants got together, aided by brokers, to discuss ways to align their perspectives concerning the exchanged information through mutual understanding of their needs. However, a lot of interpretation and misalignment resulting from complexity in tool functionalities and interoperability problems was identified between participants in most types of interaction. The BIM model in this case provided a level of ambiguity that allowed for incompatible assumptions and miscommunication more than it allowed for accommodation of multiple perspectives. While the model as an artifact should amplify the effects of the activities it reifies *in principle* while rendering them seamless, those activities introduced only more complexity and ambiguity in several instances and in most types of interaction *in practice*. Through the blind succession of tool commands and the accumulation of activities of interpretation and translation during model exchange, some of the intentions and meanings implied by participants were often concealed by those activities.

Design Intent and Model Completeness and Correctness

The dissertation study demonstrated that the BIM model can capture and convey some aspects of the designer's intention or critical design knowledge constructed in collaborative practice while it cannot communicate others. It was also shown that the correctness, completeness and level of detail of the BIM model were one of the major factors in conveying the intent of the designer and communicating design information to multiple participants. It is often assumed *in principle* that this communication cannot be facilitated to the fullest unless AEC participants work on building a full virtual 3D model such that all model elements are represented and all the information and associated attributes are exchanged among all participants simultaneously and seamlessly from schematic design and till the construction of the building. Challenges were introduced to the classical notion of the shared project model that – *in principle* – refutes any information chaos among participants and disciplines and their corresponding perspectives and arguments based on the *complete* and *correct* definition of geometric and semantic properties of BIM model elements. *In practice* however, it was shown that many other factors define model correctness and completeness, such as participant inexperience in modeling procedures, tool functionality and interoperability limitations, the lack of clear modeling and regulatory standards, and the need for supplementary communication and representation of information.

By revisiting the BIM model as a shared repository with sophisticated communication accuracies and efficiencies *in principle*, different *states* of the model were identified that describe how effective the BIM model was in conveying and capturing the intent of participants *in practice*. These states underscored issues such as the potentially unconscious design decisions imposed by the rigid structure of BIM tools, the incorrect modeling of building elements due to inexperience with tools, the loss or misrepresentation of information among participants due to incompatibilities between tools and interoperability problems, the lack of standard conventions for building elements that facilitate understanding the information needs of other participants, the partial representation of building model elements for the purpose of efficiency and reduction of modeling load, the ruling out of some of the underlying assumptions embedded within modeling or analysis tools, the required channels of communication external to the process of model exchange, and the need for forms of representation to supplement the BIM model for better conceptualization. As these states could vary across other contexts of study, the dissertation outlined the assumptions central to the study, including the type of firm under study, the project focus, size and complexity, the number of BIM and non-BIM participants, the methods of project delivery, the BIM-authoring and analysis software version used, the modeling strategies of participants and their roles in the project, and the different communication channels and model exchange mechanisms employed.

It was shown that these states of the model, as well as the intent of the model, modeling phases, and level of detail of modeling are more significant in demonstrating how efficient a BIM model is *in practice* rather than just creating a model where all building model elements are fully represented in 3D. It can be argued that the BIM model *product* yet remains similar to 2D intent drawings as long as project deliverables are not 3D models, while the goal was to embed design information into a shared repository that resembles the exact building to be constructed, only virtually. This may be true when the model represents building model elements only partially or symbolically as was the case in some instances of the SG project or when participants do not all actually share the BIM model and work on different and custom built tools. But even if that is the case and a model was represented in 3D to the fullest possible detail, and dismissing the fact that most participants have preferred to avoid the exhaustive effort and cost of modeling completely in 3D to the nuts-and-bolts level of detail, does that model guarantee a true representation and capture of design intent *in practice*?

One can argue that no single tool, platform or any form of representation or abstraction can fully capture the intentions and practices in a given context that it contribute to in terms of expression of meaning and knowledge construction. In fact, in the context of reification, a tool tends to transform issues related to expertise, motivations, goals, thoughts, and social practices into rigid and abstract forms and artifacts. In the BIM model, this translates to a complex structure and mesh of conventions, input parameters, attributes, fields, model elements and many other geometric and semantic entities. What then should be embedded in an artifact that is sought to represent and resolve the conflicting intents of different participants in a context of social practice and continuous negotiation of meaning and construction of knowledge? And why is it even critical that intent is captured if social communication is an incomparable channel that is always there inevitably to resolve those conflicts? If the BIM model could not necessarily convey the intent of multiple participants and their design activities *in practice*, and if the transferred design information was often shown to hold different interpretations, is it more important to integrate and enhance social communication aspects in BIM tools or adapt practices to current tools?

The key to answering such questions is not any different from the conventional dialectic of whether tool design comes first as a priority to enable and facilitate practice or whether practices should undertake necessary changes to match the existing tools. Here, persona description becomes inevitable to inform and enlighten the tool design process and broaden the landscape of “nebulous users” to realize and include “members” of the different aforementioned communities of practice who are primarily involved in practices of *design* and *participation*, and not just *use*. Basic drivers of tool design then would favor issues such as understanding the practices of members and multi-membership, linking the different types of primary, secondary and any emerging communities involved, and designing for the boundaries between readers, writers and brokers, rather than designing for just interdisciplinary collaboration between fixed disciplines of the AEC industry. On the other hand, existing tools reflect yet another dual relationship between heuristics, rule of thumb, and normative design on the one hand, and automation and mechanization on the other. Understood in the context of the latter moving into gradually replacing the former which was seen as inapt for current practices and complex designs, this transition (to BIM) has come with its own challenges and limitations. The inclination in the AEC industry to automate and standardize all workflows and processes implies a valid point and is endorsed by some of the findings of the dissertation, but requires a closer look at the "humanized" or "personalized" component, where the needs for efficient design, and personal and social practice are balanced and represented.

8.2 Recommendations and Future Work

The dissertation proposed in chapter 7 amendments to existing market reports and surveys. Future work will incorporate conducting these surveys on a wide scale, including AEC firms, owners and contractors, to identify the landscape of perspectives regarding expected benefits and value of BIM, and propose developments accordingly. As mentioned earlier, the scope of the survey will extend to include individuals from different communities of practice identified in the dissertation study. Future studies will build on the triangulation of data from these surveys, based on the variety of subjects and their background information, to provide a rich description of the diversity of interactions and means of communication in BIM-enabled practice. Based on the proposed survey and the conclusions and findings of the research study, the dissertation proposes the following recommendations and areas of future work:

The dissertation highlighted the importance of promoting correct and complete modeling as one of the ways to facilitate the communication of design intent among participants in practice. This will require the collaboration between software vendors, firms, research institutions and BIM related regulatory bodies (e.g. buildingSMART,

2011) or other client organizations promoting BIM practices in the AEC industry. The work by Sanguinetti et al. (2011) is an example of these efforts, where the primary goal is to check building model conformance with architectural design guide regulations and rules. An implicit goal is to check BIM models for correct modeling procedures by proposing a *pre-checking* system that determines missing or uninterpretable conventions or model elements and detects intersections and overlaps in building geometry. Another goal is to make sure that the intent of the model is translated efficiently to analysis packages by aligning the assumptions built in building model elements (e.g. building spaces) with associated attributes such as the area, cost per square foot, and heating and cooling load for that space, so that it represents a best guess regarding the original intent. The dissertation however proposes to revise the essence of completeness and correctness as per the findings and conclusions. Parameters and input variables do not necessarily define every aspect of the designer's intention or the nature of decision making that is considered external to the building model. For many, there is no other means to fully validate a model's correctness in the larger sense except by asking the designer himself. As much as this is true, but the intelligence built in the model should address other issues that belong to a higher level of interpretation of what building model elements denote.

The rigidity in the current functionalities of BIM tools has to be alleviated, whether it is in accepting too much information that makes it harder to generate a conscious decision or very little description of thought process that does not provide the capacity to track multiple decisions, needs and goals. Issues for consideration should focus on for example how to capture and retrieve design actions from multiple participants, not just at the low level of commands and data input but build associations between those commands, interpret and give meaning to conceptual tasks at a higher level, and expose those concepts to participants sharing the model with tailored information. In an interdisciplinary scenario, this would mean that the structural lead engineer for instance would be *notified* if the HVAC engineer "extended the depth of duct D23, clashed with beam B12", the project architect would be instructed simultaneously to "adjust height of space S08 to minimum 12.5 feet", and the interior designer would be instructed to "adjust tiling of wall A01 and A02 of space S08". This scenario is not to be confused with a clash detection session which is an afterthought process, but is a means of embedding real time social communication between participants that implies recognizing individual participants and their assigned roles in a specific project, understanding the task originally performed by each, interpreting what these tasks mean and what potential design alterations done by any participant mean for others sharing the model, reporting the ramifications individually, and possibly explaining the reasoning behind proposed decisions.

Other issues for consideration include integrating the history of design communication and the flexibility of expanding the building model repository to include elements belonging to other additional forms of representation or other software applications. Kalny (2007) suggests platforms for effective communication in the AEC industry that integrate resources and links to external files including documents, images and other references, similar to how a wiki is developed. Through comprehensive elaboration, expanding the repository in a similar manner can enrich communication especially in intradisciplinary and non-disciplinary interactions. As identified in the dissertation study, it was harder to rely solely on the building model to convey critical design knowledge among participants in early design phases and during brainstorming sessions. These phases and types of interaction were characterized by a high degree of ambiguity that requires using a lot of external resources and flexibility in using tools of individual preference. In contexts of design thinking within teams or interaction within secondary communities of practice, possible scenarios include team members sharing a platform linked to the model repository, working in different applications (BIM-authoring and analysis tools, sketching media), documenting and sharing their individual ideas using text, diagrams, sketching or modeling, and having access to a project library of documents and images and a historical record of other proposals within the team.

Another area of interest for future work involves adopting standards for modeling procedures and regulations for BIM workflows among participants. Having a unified body of regulatory requirements for firms may seem constraining for the design and conceptualization process, but is promising for achieving an acceptable level of model correctness and completeness. This can take the form of a “BIM certification” process for AEC firms and contracting companies. The purpose of this process is not to gain certification as a firm, but rather to define a set of requirements and standards for a given model and to ensure the correctness of building models as submitted. For satisfactory submission to the client organization or contractor, the BIM model has then to conform to one of the specified standards and obtain approval from a third party organization. Incentives for firms, owners and contractors have to be taken into consideration. Examples of items in the certification process include but are not limited to the following:

Intent of model: This involves defining the scope of what building model elements to model exactly and what not to model, to be defined in the contractual agreement among all participants. This implies defining whether for example the model is just a coordination model with a specific scope of modeled elements, and therefore follows a certain modeling convention and a certain clash detection method, or a fully detailed 3D model, which entails defining the responsibilities and ownership of model elements for each of the participants.

Minimum requirements for modeling procedures: This includes defining acceptable methods of modeling geometry (walls, slabs, etc.) and the minimum required input parameters for the specific type of model for each of the participants. Tasks and modeling activities have to be defined then for each individual; e.g. architect, interior designer, landscape engineer, etc. such that the scope of involvement is well defined.

Phase-specific level of detail: This defines a suitable level of detail for each design phase to be submitted to client organization for the purpose of checking against design guides, building codes or other client-specific requirements. This entails defining the scope of geometric and semantic level of detail for each phase. For instance, a schematic design model would include defining basic model elements such as spaces, external walls and slabs, while a design development model would incorporate detailed information about doors and windows, and more detailed parameters about the spaces, walls and slabs. Without these definitions for design phases, many unconscious design decisions may be integrated in the model and require intensive revisions subsequently.

Accepted methods of delivery: Based on the model intent and requirements, the method of delivery of the model has to be clearly specified. This has to be defined with the client and the third party organization in consultation with BIM software vendors.

Software developers have to play a role as well in managing interoperability issues between applications; such as between different BIM-authoring platforms, between BIM-authoring tools and domain-specific analysis tools belonging to similar or different platforms, between BIM-authoring tools and CAD modeling tools, in addition to managing modeling inconsistencies within BIM-authoring tools. Partnering with research institutions is also key in identifying specific areas of improvement in terms of interoperability, functionality and interface. From the aforementioned recommendations, integrating and bringing social media and aspects of social practice to technology development is crucial to take another step in virtual communication. Concepts and phenomena such as crowdsourcing and collective intelligence (Maher, 2010) are becoming more prominent in design collaboration research. At the same time, new communities of practice are growing that are less and less attached to local constraints and becoming interconnected with global communities of practice, where the role of shared models should extend to bridge those practices. More ethnographic studies and persona descriptions are needed within new and evolving communities of practice, especially those involving virtual communication and collective designing. Education research should focus more on core concepts of problem solving, integrated practice, collaborative and collective design, rather than on just digital design tools or abstract modeling and drawing procedures. Training in student projects should integrate problem-based (design and analysis), discipline-based (building technology, interior design, etc.) and team-based (interdisciplinary, intradisciplinary, web-based) approaches altogether to allow for early involvement and immersion in integrated practice and a better understanding of other disciplinary requirements.

APPENDIX A

CODING GUIDE

Table A.1. Coding guide for emergent categories and super ordinate categories

EXPERTISE		
1 New experiences	**Definition**	**New encounters that participants face in the project, including social encounters, work experiences, involvement in types of projects, use of new tools, concepts, or methods**
	Example	**B1**: *(A1) is relatively new to our firm…he came from a firm that was using Revit so he has more Revit experience than I would say to other people…but (A3) again she had some prior Revit experience…it has been a while since she used it so she has just been through training…but I don't believe she and (A1) had probably worked on a project together…and I don't know if either one of them have worked with (A2)…and chances are they may or may not have worked with the consultants before.*
2 Expertise with using the tool	**Definition**	**The nature and level of expertise of participants in the project in terms of their proficiency in using BIM tools**
	Example	**B1**: *The reason people need support is because they only see the problems that they come across…I mean in support we see so many different projects so many different people…and as you start seeing the same issues over and over…it's like…because we see problems on a much…it's like accelerated learning…eventually if you work long enough in Revit you might see every single thing that I see…but because I get questions from every single project I see a lot more and know a lot more about it more quickly than the average user.*
3 Work experience	**Definition**	**The individual and collective expertise of participants within a team in terms of domain specific knowledge**
	Example	**M2**: W*e've worked together long enough we kind of*

Table A.1. continued

		know when we look at a building where the best place would be for certain elements – I mean there is always water service stuff where (M1) has to have this here and electrically it's the same kind of thing – we kind of make sure that those are separated – I think it's just an understanding of working together and we've all been in the business long enough to know that there are certain things – we just know that the plumbing guys or the HVAC is going to need some space here.
LEARNING PROCESS		
4 Learning to use the tool	**Definition**	**The experience and learning gained along the course of the project with regards to learning and interacting with capabilities of BIM tools**
	Example	**C1**: *I'm not saying that eventually the tool won't be able to do that but everybody is just going through this learning process now and figuring out – and the contractors are figuring out that in order for it to do what they need it to do most of the time this is my understanding.*
5 Learning how to put a building together	**Definition**	**The learning process involved along the course of the project in terms of details of design and construction**
	Example	**A4**: *I want to know how to put a building together…I don't care if it's going to be Revit or if I will have to draft the damn thing you know…I have to learn how to put a building together…and not only that I want to learn how to put a good building together…I want to see…and I'm very glad that I have this opportunity to get into a project from the beginning till the end.*
TRANSITION TO BIM PROCESS		
6 Resistance in accepting BIM process	**Definition**	**The resistance of participants, teams or disciplines at large to the philosophical idea of BIM, using BIM tools and its value to them and to practice**
	Example	**M3**: *I can see a reason for resistance to it from some of the older generation but I know people that still hate using CAD and won't use a CAD program – we'd draft it up and then hand it redlined to somebody so but that's*

Table A.1. continued

		just part of culture – it's part of growing up drawing you know.
7 Gradual adoption of BIM tool functionalities	**Definition**	**The gradual transition to BIM in terms of processes, platforms, and mindset, and its main strategies and procedures**
	Example	**S3**: *Yeah there was a transition period where we had – detailing being able to draw sections is by far the most involved – and to be thrown in and have to do that without knowing Revit would have killed us production wise because it would have been just me working in plans and the model it would have been any other engineers that we get on board just to get the deadline out or anything like that – they would have to have Revit experience and at that point there was only two of us – but that's no longer the case – we are making a real big push to do everything in Revit*.
8 Pressure to adopt BIM process	**Definition**	**Pressure of market, discipline, firm, team, or individual to adopt BIM tools and functionalities**
	Example	**A4**: *I mean they are great but they are resistant to using the other software – and I understand because they invested a lot in training for Revit and the transition from one software to another especially in this case when we're talking Microstation and Revit – it's not like we're talking BIM to BIM – we're talking Microstation to BIM or non-BIM to BIM – it's a different kind of thinking so there is a lot of resistance from our part you know – and there is a lot of money invested and they want to run things smoothly*.
AFFORDANCES WITH RESPECT TO THE TOOL		
9 Visualization capability	**Definition**	**The capacity of visualizing building model elements in 3D space and navigating through space to understand the designed space**
	Example	B1: *Things as simple as you know we're looking at a 3D model and we're kind of got a section cut through this atrium space and the mechanical engineer said oh well let me show you what we were thinking about how we were going to put air in that space..and the architect*

Table A.1. continued

		was there and would say well this is a column cover over here…you got a lot of space over here…you can see if you go up and around…so three dimensionally they can start figuring that out…and I think it's tremendously useful.
10 Parametric flexibility	**Definition**	**The capacity to use the parametric structure of BIM tools to modify and adjust building elements easily and efficiently**
	Example	**P1**: *It will be simply probably a shorter building…won't change..it doesn't change the plan organization strategy at all…we usually start by developing a building concept that is fairly easy to modify because we know that these things are going to take place…and to have a building that is so dependent on knowing what every piece is today and if any one piece changes you need to rethink the design we found is not an appropriate strategy for us.*
11 Efficiency and accuracy	**Definition**	**Achieving a degree of efficiency and accuracy in subsequent phases of a project by using the capabilities of the tool**
	Example	**A3**: *I can do it all in Revit…like I said I'm faster in the computer than out…it looks better…it makes more sense…I do it on the computer…and to me it's more realistic because it's actually…we have to work it out realistically to get it to show the idea… I mean even if it's just a …you know I may not be doing it absolutely correctly but is there's say a special piece of millwork…a specialty display case or something like that I'll just quickly create some modeling boxes and things…because I can do that fast ..it kind of works it out because I know it's real dimensions and really going to work eventually…because a lot of the times people will sketch things and it's not to scale and doesn't work…yeah I think I work much better on the computer.*
12 Concept-ualization and reflection	**Definition**	**The capacity of BIM tools to aid conceptualization, developing design alternatives and reflecting on ideas**
	Example	**A1**: *I also did some very basic Revit massing just to show proportionally how much labs and office space and things we're looking at and how are we looking at*

Table A.1. continued

		using kind of the lab module of 10 foot 4 and certain structural things we have in mind of how we usually set up a building.
13 Extraction of useful information	**Definition**	**The capacity of BIM tools to generate useful information in multiple forms for participants**
	Example	**S1**: *It's more of a – it's a table – it's not a full spreadsheet – it'll kind of go through floor by floor and it has different packages so there is a graphic package for beams so it will (unclear) on a floor by floor basis and then give a summary of all the steel (unclear) beams and girders in the building and a summary of weight and then you can go into a second package that's the graphic (component?) it will give you a summary of the total pieces and weights – and then the third component is the lateral package – it will do beams and columns and braces that are part of the lateral system of the building that you've defined – so we may have 50 columns we'll say on the project – the ones that you've defined to be your lateral columns will not appear in the graphic column component – so by summing those three packages which you have to do manually you can get a good idea of the thing – and when it prints it out it's maybe a three minute exercise to just go through and cut off the numbers and you know the gross square footage of your building.*
14 Tracking information along the design process	**Definition**	**The ability to keep a record of project information, elements and modifications throughout the phases of the project and beyond**
	Example	**B2**: *Once they get the facilities people to understand it they can track all the modifications – maintenance of a building like fixtures and when they need to be changed – just every element of the building, what needs to be changed, what has been changed and how it's changed – what manufacturer, cut sheets, I mean if you can click on any kind of element like a drinking fountain or something and a cut sheet pops up, manufacturer data, how to replace it, who to call, who installed it, all that stuff comes up – it will be great, and then if you are doing a renovation you could use that model to build on.*

Table A.1. continued

AFFORDANCES WITH RESPECT TO COLLABORATION		
15 Conflict detection and resolution	**Definition**	**The ability to do clash detection and automatically check BIM models from multiple participants for conflicts for coordination purposes**
	Example	**S3**: *The theory is – I haven't used it – I haven't had the opportunity but the theory is that you can run coordination review with the architectural – and this is the reason having it in Revit and not 3D or AutoCAD 3D is because the MEP is modeling a duct and it's got all this metadata with it that it's this high and this wide you know that kind of thing – and then it runs coordination review against the structural and it's supposed to spit out hey these coordinates are being shared between the two – between the duct and the beam – that's not a good thing and it will say look at this where it will highlight the instance and show you – like I said I haven't done that but there are coordination review issues with the architect.*
16 Coordination of information between participants	**Definition**	**The capacity of BIM models to allow multiple participants to coordinate and discuss different types of information**
	Example	P1: *How can we create 3D models of rooms…usually in the programming process we talk to our clients about well what do you use a room for…what equipment goes in it…how many people need to go in it…and what seating arrangements or what lab bench arrangements suit you best…and we would after drawing that …sketching that…we would usually create two dimensional room diagrams….they would say oh yeah I understand that's a 900 square foot room and that's the way I'm going to use it or that's the three ways I'm going to use it…well Revit gives us this tool that then shows them in both two dimensions in plan view and also in three dimensional view…and a lot of people will understand the three dimensional drawing in an easier fashion…so there's the visualization communication aspect that Revit allows us…BIM allows us to use more effectively to communicate with the client.*

Table A.1. continued

17 Shared repository of information	**Definition**	**Having a single consistent and accurate model that is shared by all participants in the project**
	Example	**M2**: *They bring everybody into one room – all contractors and engineers and architects – all work together and develop a Revit model and then that's the drawing – they use it – they convert them to their manufacturing drawings and the duct work – that 3D model never gets flattened and produced into a flat set of drawing – in that world you never needed to have a detail page because you could take a snapshot out of any piece of it in the building you want to get your detail – I think that's really forward thinking and I don't know when the rest of the world will get there – so what we're doing here today I think is where we will be for a while – designing a building and then doing our standard construction details that kind of give you more detailed information on how to connect up water heaters and how to hang transformers - these kinds of things that we setup to show in a separate page*.
INCOMPATIBILITY AMONG TOOLS		
18 Incomplete information from the tool	**Definition**	**The degree of completeness of semantic or geometric properties in a building model in any given tool**
	Example	**C1**: "*I mean this level of detail to be able to extract this level of detail there is some things that we'll never be able to extract from Revit so there is always going to be even if we were let's say best case where there is Innovaya or someday Revit will talk to Excel or Timberline and you can export items directly out of Revit into Excel you are still going to have to come back in and sort of fill in gaps*.
19 Incorrect information from the tool	**Definition**	**The degree of proper representation of semantic or geometric properties in a building model in any given tool**
	Example	**M1**: *Some of the models that we brought in they have some problem with that – like you have a piece of equipment that you show on the third level – it starts showing throughout all three levels and we don't know*

Table A.1. continued

		how to – like we have to find it in a different model or hide it – so there are many little things that you need to do in addition to what we used to be doing in CAD.
20 Discrepancies in conventions and parameters	**Definition**	**Tools lacking a consistent set of conventions for building elements such as spaces, types of walls, partitions, doors, making it harder in terms of coordination and smooth flow of information among participants**
	Example	**C1**: *The way that some of these integrators work is that they can say well there is what they call mapping where if you got Timberline over here an Excel spreadsheet – let's say Timberline because they have more standardized line items and then you've got from your translation software or from your Revit model things – unless the language is exactly the same – definitely it's not going to happen in Timberline because Timberline has their own – unless we work backwards and say let's use Timberline's naming convention and call all of our things the same things that's not going to happen either – but there is this process of mapping or linking where if you are in your translation software here and you've got all these items that came out of the model at some point you would have to say ok this equals that and these are the same thing and this is the same thing as that.*
21 Interface and data transfer problems	**Definition**	**Problems associated with the translation capabilities of different modeling and analysis software packages when files are exchanged back and forth among participants**
	Example	**M2**: *I know that to use Revit within HVAC to run your HVAC load calcs and to determine what your heat loss is so you're scanning windows and determine how much air conditioning or heating you need to put into a space – if that's all integrated in your model eventually it saves us time because you enter it one time and then you use that same model as your input – but today a lot of times we have to – we have our design software or our drafting software but then we have to take that information and model it into some other software – use that output then to size systems that we then put back in – you know we're back and forth in and out between different systems – we can't share the same input data*

Table A.1. continued

		and I think any time we can start sharing the same input data we're first of all more accurate and we can get results quicker – the feedback loop is great because it allows us to adjust as we do things.
COST OF TOOL FOR PARTICIPANTS		
22 Cognitive overload	**Definition**	**The cognitive burden that participants experience while using BIM tools**
	Example	**A4**: *How am I supposed to have that knowledge – I don't even care if it's storefront at this point – I'm trying to compose the damn façade – I don't care if it's a piece of plastic right now – I don't care if it's a storefront – I'm going to assign it to be a storefront later if I wanted to – why would I have to decide it's a storefront knowing that it's going to cut in a certain way through the wall – that is a stupid thing because the more I decided it's a storefront it's going to lead me to certain kinds of design because it cuts in certain ways through the damn wall – so then where does that leave us? To know – to have that knowledge – to have that detailed knowledge about the storefront and what the storefront does and know the limitations of it – you know what I mean – you still need detailed knowledge – you need a vast amount of knowledge to treat this as a tool and improvise.*
23 Design conceptual-ization problems	**Definition**	**The cost associated with using BIM tools in early design phases, where most design decisions and requirements are still at an abstract level**
	Example	**P1**: *I think you know one of the impacts is that you don't have to make earlier decisions but if you are able to you can create efficiencies...you know in the very earliest phase in schematic design if you want to draw a room wall you draw a six inch wall well…as you move into design development and construction documents you need to know exactly what that wall is made of…how many layers of gypsum wall board…where the steel studs are…how thick it is…it may not be six inches any more..it may be six and a quarter inches or five and a half inches…and you know you have the flexibility of changing those things certainly…if you could say in the*

Table A.1. continued

		schematic design phase that I know that that's a five and a half inch wall with two layers of gypsum wall board on either side of a certain dimension stud and it never changes there is great efficiency in that but the design process just doesn't work that way yet..and it shouldn't be…you shouldn't be hampered…it shouldn't slow you down in thinking about well what is that room used for…you shouldn't have to stop at that point and think about…is that wall six inches or six and a half inches or seven inches.
24 Ease of use	**Definition**	**Degrees of ease with which the functionalities and capabilities of BIM tools can be used by participants**
	Example	**A1**: *Back when you had CAD you just drew a symbol for a steel column and that was that – you don't worry about moving but now you have to check everything because things will move, and I've come across that a lot, beams go up and down 3 inches and now your drawing doesn't look the same, and that can happen the day of printing, so it's just one of those things.*
25 Need for interaction with participants within team	**Definition**	**The need to communicate with other participants within the team and not relying solely on model updates, information extracted from models, or other representations**
	Example	**P1**: *Somebody may be studying the lobby space and how we get a stair from the ground floor to the upper floor or (A3) may be working on three or four ways to arrange the faculty offices and the conference rooms – (A1) may be working on the structural system of the building – and so all of that has to come together, so we usually try to put that up on the wall and talk about it and get everybody aligned on the same message and make decisions – and then everybody is aware of what we are doing.*
26 Need for representations external to the tool	**Definition**	**The need for forms of representations other than BIM tools (e.g. sketches, images, physical models, verbal communication, etc.) to conceptualize or to convey information internally within the team or to other participants, implying that the BIM model alone is not sufficient to convey that information effectively**

Table A.1. continued

	Example	**A1**: *Without taking that any further I kind of go off to the side and do a quick little massing model with floors based on kind of the footprint and then over that I sketch…we start doing hand sketches and things over that to get an idea of what the building…you know…to get an idea of what the materials are going to be but how they work together is going to be the trick.*
COST OF TOOL FOR TEAMS		
27 Rigidity versus flexibility	**Definition**	**The challenge for disciplinary teams created by the degree of precision and rigidity required by BIM tools, especially in early design stages**
	Example	**M2**: *If we were within a few feet it was ok because the contractor filled that gap – today the model brings it to that point and shows really all the fittings to that point – so it's just so much detail and the Revit software wants that detail – and it kind of doesn't want to move forward if you have it or you don't fill it.*
28 Cost of modeling in 3D	**Definition**	**Issues associated with forcing all disciplines to extensively model their building components in 3D**
	Example	**M1**: *Yeah but then the drawback here is that in plan view you have so many more details like the (chase?) feedings that in plan view very often hook weird – and I'm not sure the plumbing contractor even wants to see it if we draw in single line – sometimes too much is not good.*
29 Coordination and management overload	**Definition**	**The cost associated with managing the complexity of BIM models and tracking inconsistencies or inaccuracies across teams**
	Example	**B2**: *Once a project gets built the bigger it gets the harder it is to track where all the inaccuracies are…and so they are really trying to focus on all of that stuff…and so there is a lot of planning involved.*
30 Need for interaction across teams	**Definition**	**The need to communicate with other participants across teams, and not relying solely on model updates or information extracted from models**
	Example	**S1**: *Now that we're out of DDs and into the CD phase the meetings will – especially at the front end we need to*

Table A.1. continued

		get on the phone with (A2) and say we need to get together and talk about relief angles and where suspended brick will be and lintels and headers and some of these components now that they are really out there.
DISCIPLINARY POSITIONS AND PREFERENCES		
31 Relevant versus irrelevant information	**Definition**	**The type of information, objects or elements that participants consider relevant or irrelevant to them or their disciplines**
	Example	**A1**: *I found that while Revit can do 3D site…you don't need a 3D site most of the time…it's irrelevant…yeah it's such a flat site it's irrelevant...and the 2D drawings will work fine…because at the end of the day we print 2D drawings anyway…so we don't need to spend time on that.*
32 Perception of BIM representations	**Definition**	**The way different participants perceive representations or elements generated by the BIM model**
	Example	**A4**: *And that's when I got very confused because of the fact that this was a stacking diagram and not a plan…and then I said ok this is a plan if you are telling me to study only the façade but in fact it is only a stacking diagram…so here is where we all fell into a trap…because of what Revit does…you know…which is providing so much detail.*
33 Personal preference of tools	**Definition**	**Preferred tools for each discipline throughout the project phases, seen through the views of its participants and teams**
	Example	**M1**: *Like CAD is flexible – you can in five seconds using different methods create anything you want and produce a plan very quickly – Revit demands much more time and it had many more limitations as far as you can figure what commands are available to you and probably it's going to get better with time and maybe 2011 is a little better and then 2012 will offer more flexibility but it very often limits via speed because of its laws of physics built in.*

Table A.1. continued

34 Level of confidence with the tool	**Definition**	**The degree of trust and confidence that each participant, team or discipline has in information extracted from building models**
	Example	**B1**: *When I'm the estimator and I do the take offs I have a lot of confidence in all these numbers that I see in front of me because I know that I counted these doors and I know that I saw that type of wall…if I get handed a sheet of paper from the team that says there is this much wall and I don't know where that wall is or what you know…why or what or maybe it's a generic wall because of where we are in the project and they haven't decided if it's a masonry or whatever…there's a disconnect there.*
35 Human judgment	**Definition**	**The subjective component in the design process where some issues require human judgment and common sense to weigh things and cannot be done in a fully automated fashion that relies only on information generated by the tool**
	Example	**S1**: *I'll just go through and sum those three components from RAM and divide it over the 80000 square feet – and I've got it down to about 8.5 pounds a square foot now and then I usually throw a 10 percent factor on to it at this early stage just in case there are some changes - so I told (A2) to allow 9.5 pounds a square foot for the structural steel in this last release*.
36 Desired functionalities	**Definition**	**The different capabilities and procedures that each participant feels are missing and wishes to be implemented in future systems**
	Example	**M1**: *Well maybe a little of automation would be higher than what was promised – but I don't think it was delivered because – or if there was a universal library of symbols would be available to us and the architect at the same time so they would be starting their projects using those symbols*.
37 Information needs	**Definition**	**The information that the participants consider crucial for the progression of the project**
	Example	**M2**: *It's the fact that you know we don't have the information available – you would really like to go to the manufacturer's webpage of the product you would*

Table A.1. continued

		like to use and pick up their family and put it in to your drawing but it's probably not available then you search for something that is similar and you use that as a placeholder so you know we're making due – and that's the first (great) side of it – we'd like to just see it move faster and that's going to be the course of how it's going to work for a while.
INTERACTION WITHIN TEAM		
38 Conflicting positions within team	**Definition**	**The argumentation and the different positions and views among participants of a single team**
	Example	**A4**: *I personally don't think that the discussion should have been taken that direction because I could foresee the end result – at that level you have to talk about what the building does – the larger picture you know what I mean – not if it's made out of brick or if it has a pitched roof, that is irrelevant because – I don't think there is anything wrong with a pitched roof or brick in itself you know but there is something inherently wrong about saying that there is only one way to deal with it – there isn't – but anyway that was a dangerous road – to me it was a dangerous road to go – our team chose to take that road and we got into this.*
39 Team reconciliation and negotiation	**Definition**	**The process of negotiation between participants in a single team to arrive at a common understanding and a final decision**
	Example	**P1**: *We have a robust discussion about that and then try to align our internal firm goals for the project with the client goals and then make sure that there is a sort of buy in at the team level so that we don't have you know one person in the team interested in doing something that is not aligned with the whole mission of the project.*
40 Pressure within team	**Definition**	**Pressure on participants to work on certain tasks or in certain tools during different phases of the project**
	Example	**A4**: *After the presentation (P1) actually said ok you need to get – we need you in Revit because there is always a disconnect and this will allow (A1) to focus on other stuff – seriously it's not fair he can't do everything – he is doing tons of stuff – it's not his fault that I am an*

Table A.1. continued

		idiot with Revit and I have to push it – so everybody is encouraging and they kept pushing me to get into the Revit model and take over this thing – if I draw something I should be able to – if I draw something in sketch or if I think about something I should be able to draw in the model.
41 Status and comfort level within team	**Definition**	**The nature of the structure and system of authority within the team, as well as the level of confidence and comfort that each participant holds for others within the team**
	Example	**A3**: *(A1) and I…I think we're going to have to figure out how to work together because he is in charge of the file…which is fine…but he came from a different company…I came from a different company and now we're back here…we're both on Revit and so…I'm going to kind of have to follow his lead on how he sets up the file…so I think that may be a little frustrating…we'll see…just because we're used to work in different ways in Revit.*
42 Assignment of roles and tasks	**Definition**	**The specific roles and responsibilities that each participant is assigned within the team, and the interactions that occur among participants based on these roles**
	Example	**S1**: *(S2) and I have pretty much handled it since the beginning and then (S4) who stamps the drawings – he and I would touch base – I kind of keep him abreast of what's going on and he'll flip through the drawings in every 2-3 weeks to make sure he understands where things are going – but (S2) and I we handle mostly everything – and (S2) does more of the production work of handling the Revit model and structural modeling and then I'll kind of come back and review and smooth the designs and make sure that everything is going appropriate from that and I do the detailing of edge conditions and façade backups and then the more in depth interface with architectural and mechanical.*
43 Support structure within team	**Definition**	**The mechanisms of support within a team, including both technical support and additional workforce**
	Example	**B1**: *I think the more knowledge that is gained*

Table A.1. continued

		throughout the firm the less likely they are to come to me…and part of that is…it's something we try to deal with...we try to deal with it in support anyway…I don't know that it's any different than any other kind of support…there are certain people that are reluctant to ask for help because they feel in some way it makes them look like less of a person..and so they are more likely to ask their buddy who they are comfortable with…who they feel they may not judge them versus me who they make think is an expert…number two that I may think they are an idiot if the question in their mind should be easily answered…so we've tried to develop ways of getting around that…we tried to develop what we call our CAD mentoring program where we identify people in studios..that they are going to be a resource and that we would meet with them.
44 Insufficient BIM data input	**Definition**	**Input of data (parameters and variables in BIM tool) that is not enough for the use of other participants while pursuing their tasks**
	Example	**C1**: *Here is what I keep saying when we talk about Revit and how we are going to do that is that as an estimator what I do – the way I do what I do – is let's say a schematic design where we don't necessarily know what a door is going to be or whatever I go ahead - so that I can tell them what my price is based on – I go ahead and make a decision what that door is or what that exterior wall simply is whether it's brick – you know they may tell me it's going to be a masonry building or whatever but they don't know beyond that.*
45 Team knowledge history	**Definition**	**Domain specific knowledge and procedures that are collectively constructed through precedents within the team**
	Example	**S3**: *We are working on them and that's part of the thing our committee is doing is we're trying to get together and decide on exactly how we want to show this – you know here is a typical detail we've used for years and here is how it's been tweaked by all the different people let's put it back to one common that we've heard everybody's arguments as to why they like to do this and why they don't like to do that and let's try to get that then we'll draw it and it then will be in our Revit details.*

Table A.1. continued

46 Disconnect among participants	Definition	**Disconnect due to striking difference in design or tool expertise among team participants**
	Example	**A4**: *Now let's talk about Revit because that was a little bit of a mess because (A1) and I were at different levels completely different levels and I tried to get into Revit and throughout the design I kept doing the hand drawn sketches and he was doing Revit and there was always a disconnect*.
INTERACTION ACROSS TEAMS		
47 Conflicting positions across teams	Definition	**The kinds of conflicts that teams experience with respect to one another in terms of methods, concepts, workflows or tools**
	Example	**S1**: *So even though it's just points and spaces and lines I feel comfortable with the take offs that RAM provides me for materials of quantities for columns and beams and girders and braces – and so I'm not sure where I'm any different from the cost estimator*.
48 Reconciliation and negotiation across teams	Definition	**The process of negotiation between the architectural team, consultants and/or the client to arrive at a common understanding and a final decision concerning a specific issue in the project**
	Example	**A1**: *We can do a really modern building but I think for this client they prefer a more traditional approach and so we're trying to kind of negotiate what we want in the design right now.*
49 Concurrence among participants	Definition	**The level of agreement among participants from different teams concerning approach, workflow or use of tool**
	Example	**E1**: *It's pretty good because I've worked with them before on other projects and they are also in tune with sustainability*.
50 Scope of involvement	Definition	**The scope of each team in terms of processes, methods, workflows or tools**
	Example	**L2**: *Yeah we have our own cost estimating process that we use – it's generally a separate thing for us – we do it outside of the architect's supervision – we're doing that*

Table A.1. continued

		directly for the client.
51 Understanding needs of other disciplinary participants	**Definition**	**Recognizing and understanding what other teams require throughout the process in terms of workflows, processes or required information**
	Example	**S1**: *I have to be careful how I say this – the mechanical systems don't necessarily have to stay in lock step with the architect because as long as they are given a good idea on the front end of what they anticipate they can kind of go on and work on their own and then come in later in the game with their systems but with what we do we have to stay pretty well in keeping with them otherwise we hold them up and once you fall behind it's really hard to get caught up again.*
52 Participant status	**Definition**	**The authority and power structure among the architectural team, consultants and the client**
	Example	**E1**: *The first issue we're going to need to address is the building orientation because the client asked us to put it in the exact wrong way…it's a long bar building …the long faces are east and west oriented…so we just need to make sure that we are not going to be cooking people (unclear) that's where I am going to start with them.*
53 Developing workarounds in tool	**Definition**	**Devising ways and methods in the tool that, according to the teams, are more suited for the practical and collective progression of the project**
	Example	**A1**: *We'll try to avoid…and we'll have to work on this…about trying to avoid a lot of modeling in there…if it's not necessarily being modeled I don't think it needs to be drawn in 3D…usually if it's seen in 2 views I'll model it…if it's only seen in one view it can be drafted…that all depends on each object and each thing but try to keep the models as small as possible because I've got into projects where you can't do anything in it…just really wrecks the project.*
54 Patterns of exchanging information	**Definition**	**The types and rate of exchange of physical and digital documents among teams**
	Example	**B2**: *DD – it would be more like every other – especially*

Table A.1. continued

		before submittal – like every Friday and sometimes when you are getting closer and closer you may need to do – if there are significant changes you may need to do every other day or something like that.
IN PRINCIPLE VERSUS IN PRACTICE		
55 Expectations of BIM	**Definition**	**The expectations of BIM capabilities based on publicity, and the actual experience of participants while unfolding these capabilities in practice**
	Example	**M1**: *When we were introducing ourselves to Revit we were told that at any point when you want to change something you can just move it and it just changes in all the views – yes it does but if you have to move a piece of a plumbing system that is connected to five different pipes the moment you disconnect it those systems go inactive and so it's not as easy as it sounded initially.*
56 Workflow efficiency	**Definition**	**Perceptions of the claims about efficiency or automation in terms of workflows, exchange of data, or extraction of information using BIM models, versus the ways they are enacted in practice**
	Example	**M2**: *What would be even better – the detail that we're drawing to – it would be nice if that file could be handed off and used to estimate materials so that as we're designing we could figure which is the most cost effective way to do this – but today we're drawing to some detail but the system is not functioning that well.*
57 Phase of engagement in the process	**Definition**	**Participant perceptions of claims involving BIM tool use in design phases especially early phases, versus how each of the participating disciplines actually employs them according to their needs**
	Example	**A4**: *I wish we wouldn't toss away all the other software and have just one software be it Revit be it SketchUp be it anything else that we're going to use and that would be the only one – I wish we could use Revit just as any other tools we're using and just to be one tool among many and if we feel comfortable with using SketchUp or MicroStation or whatever in different stages of the project we should be able to do that – what bothers me is we need to use Revit from the beginning till the end…I'm very sure that Revit is absolutely a wonderful tool starting from a certain point in the design process.*

APPENDIX B

INSTRUCTIONS TO REVIEWERS

For the purpose of validating the analysis and coding process of this research, the attached document provides a guide to a sample of the codes used by the author in analyzing notes and transcripts from interviews and meetings. The research questions are first listed down to give the reviewer an idea of what the main issues and questions in this study and how the selected codes attempt to address and tackle these questions. A list of all to-date codes used in the study is then presented. This list includes all codes and their higher level categories. The goal is to give the reviewer an idea of the overall implemented scheme and the relative weight (instances of occurrence) of the codes in general.

A brief coding guide of a sample of codes is then presented. These codes are more relevant to the sample transcript that is provided in a separate document (according to the author). The coding guide provides a short explanation of what each code represents in addition to an example extracted from other transcripts analyzed by the author, in order to give the reviewer more insight into the meaning and context of use of the presented codes. A numbered list of the sample codes is provided. Additional rows are provided in case the reviewer wishes to add other codes. A sample of the coding procedures that should be used by the reviewer is shown (figure B.1).

A sample transcript of an interview with one of the subjects in the study is provided in a separate file. The subject is a cost estimator and in-house consultant at the architectural firm. This interview was the first interview with the subject. The reviewer is asked to read the transcript carefully and use the provided codes and any other additional codes that he/she sees appropriate. In the sample transcript file, the reviewer should use the “insert new comment” command to highlight the necessary phrase or paragraph and write down the serial number of the used code (e.g. write “21” for code #21: Interface and data transfer problems). If the code is a new code that is introduced by the reviewer, he/she should first write the introduced code in the additional rows and then write the serial number of that code in the inserted comment. At the end of the transcript, the reviewer is asked to write down his/her name and date of completion of review, and send both documents after renaming them (e.g. Coding guide_Reviewer name.docx, and Sample transcript_Reviewer name.docx). A meeting will then be held between the author and the reviewers to look at and validate his coding scheme according to their interpretation.

Thank you for your participation

Sample coding required from reviewer

Protocol Title	An ethnographic study of interdisciplinary collaboration in BIM-enabled architectural practice (Main 03/23/09v1)
Document Code	I1-C1-05242010
Type of document	Transcript - Individual interview
Site	Architectural firm
Subject	C1 (Cost estimator at architectural firm)
Project	SG medical technology building
Method of recording	Audio taping
Date Recorded	05/24/2010
Duration	61 minutes

	C1	I’ve been here – I’ve been here for 17 years – primarily doing – I mean I like – rather than telling you I’m an estimator I like to tell I’m in preconstruction because the responsibilities sort of range from early – early budgets – pre-design budgets all the way up through doing detailed CD estimates so – and other things too but I mean the principle behind it was to have in house expertise on costing so that during the design process we’re making informed decisions as to the cost of materials and systems and that kind of thing and hopefully not getting down the road to DD or CD basis of design and having to do redesign – in theory that’s the way it is supposed to work
	I	In theory – so how does it really work?

Comment [*1]:** 3

Comment [*2]:** 45

Figure B.1. Sample coding required from reviewers

APPENDIX C

SAMPLE TRANSCRIPT

Table C.1. Extract from interview transcript with the cost estimator (C1)

I So what kind of information do you need to tweak really or that is not in Revit that you need more information about?

C1 It had mostly to do with what we were naming elements and how descriptive those – not just the names because you know there is a lot of data that gets attached to an element – and I'm not a Revit guy so I have an understanding of it that is pretty basic – but as an example a project that I was working on where we talked as a team about the quantities that we can extract from Revit and so as I'm doing take off I'm saying ok I'm going to get that from Revit – doors for instance – a door schedule you know – the count items they should be fairly simple items to extract from the model and fairly trustworthy so I go through this whole process as usual at the end of the process I'm scrambling trying to meet a deadline so I pull out the door schedule to plug that in and the information just isn't there – here is this door but the naming convention was such – and I'm talking about the printout that I get from the architectural design team – the naming convention is such that it doesn't tell me what I need to know – it doesn't tell me if that's a flush door – it doesn't tell me if it's got a narrow light in it or if it's a half light – it doesn't tell me if it's wood or if it's hollow metal – it doesn't tell me the size if it's a 3 foot or 4 foot door or if it's a 7 foot or 8 foot door – it doesn't tell me if it's an A or B labeled – it doesn't tell me if it's non-rated – it's just whatever quick name they slapped on it so that they would know what it was – so the trick was to get on the next project is to get more of that information loaded – and that's some of what we are trying to resolve internally is to get enough information attached to that element – that door – so that when we print it out in Revit schedule or it gets exported through Innovaya or whatever to an Excel spreadsheet that there is enough information there for the person who is pricing it to know – to distinguish it between one and the next item – especially when you are talking about a CD estimate where you can have 8 to 10 different types of doors

I Yeah and is it also happening at later phases not only at early phases?

C1 Well and here is what I keep saying when we talk about Revit and how we are going to do that is that as an estimator what I do – the way I do what I do – is let's say a schematic design where we don't necessarily know what a door is going to be or whatever I go ahead - so that I can tell them what my price is based on – I go ahead and make a decision what that door is or what that exterior wall simply is whether it's brick – they may tell me it's going to be a masonry building or whatever but they don't know beyond that

I Do you make some assumptions then?

C1 Yeah I make assumptions so what I maintain to the designers is if I can make these assumptions then you can make those assumptions so rather than building – and I haven't checked with them lately I don't know if this is still the direction we are going – it didn't meet a whole lot of resistance – but from an estimating standpoint I take the line items that I use at construction documents at a very detailed level and I use them in the schematic phases because I will go ahead and look at a floor plan and say that wall is probably going to be rated so I'll price a rated wall there and make those kinds of assumptions – so if I can do it I know that they can do it and rather than having two sets of libraries one for preliminary design or schematic design and another more detailed library for DD and CD drawings it will make more sense to me if they have one library – within that you may have generic elements that they use very very early on but we have our own office sort of partition type – we call them wall tags – so that when we draw a wall you put just a flag on it that says this is 1S49G and everybody in the office knows what 1S49G is – so like I say when I do my estimates even at schematic design I'm saying you'll get my estimate and at schematic it will say this is a 1S49G – I go ahead and make that kind of a judgment decision and say this partition is probably going to be rated, well obviously it's going to go from floor to structure but it's probably going to have bat in it anyway

I But you don't go in discussions with them? You make the assumptions and go forward with that?

C1 That's the way it's done now – in theory what I think the way that it should be done is rather than me making those assumptions they are more qualified to make those assumptions than I am in some instances…and that's where on a firm wide basis we all sort of need to be on the same page so that we are embedding that information – information that I need – now here is the trick is people out there selling BIM – contractors and architects selling BIM to owners and how much time it saves and how the model can be handed over to a contractor and the contractor can extract all this information out of it but 1 the information is not in there – and I think of myself here as a contractor – at least my perspective is similar if not the same – and if I can't extract what I need out of the model then the contractor can't either – so the guys that are selling it – the DPRs that are selling it to owners as this powerful tool I mean what are they doing? They are taking the architect's model and they are rebuilding it – they are rebuilding the model in a way that is useful to them - I mean that's not efficient

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